2008-09

Portable signals analysis solutions using Signalworks : a process guide for analysts and students

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

PORTABLE SIGNALS ANALYSIS SOLUTIONS USING SIGNALWORKS®: A PROCESS GUIDE FOR ANALYSTS AND STUDENTS

by

Eric W. Sears

September 2009

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2009	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE Portable Signals Analysis Solutions using Signalworks®: A Process Guide for Analysts and Students	**5. FUNDING NUMBERS**
6. AUTHOR(S) LT Eric Sears	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

Signalworks® is a signals analysis software suite designed to be installed on Windows and Linux portable computing platforms. The demodulation applications within the program offer considerable processing capability for a variety of signals coupled with a graphical interface that is both easy to use and configure. This thesis examines the process of building test signals within Signalworks® and then processing them with the available demodulation applications to define important parameters used to identify and analyze signals. Although Signalworks® version 4.0 is unable to demodulate Orthogonal Frequency Division Multiplexed (OFDM) signals often used in wireless communications, it can process Binary Phase-Shift Keyed (BPSK) and Quadrature Phase-Shift Keyed (QPSK) signals used in the 802.11b standard. While future versions may include OFDM demodulation capability, this analysis includes the feasibility of using Signalworks® in a lab environment to demonstrate and educate students on signal characteristics including wireless communication signals.

14. SUBJECT TERMS Signals analysis, portable signal processing, Signalworks®	**15. NUMBER OF PAGES** 125
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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PORTABLE SIGNALS ANALYSIS SOLUTIONS USING SIGNALWORKS®: A PROCESS GUIDE FOR ANALYSTS AND STUDENTS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION WARFARE SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Signalworks® is a signals analysis software suite designed to be installed on Windows and Linux portable computing platforms. The demodulation applications within the program offer considerable processing capability for a variety of signals coupled with a graphical interface that is both easy to use and configure. This thesis examines the process of building test signals within Signalworks®, and then processing them with the available demodulation applications to define important parameters used to identify and analyze signals. Although Signalworks® version 4.0 is unable to demodulate Orthogonal Frequency Division Multiplexed (OFDM) signals often used in wireless communications, it can process Binary Phase-Shift Keyed (BPSK) and Quadrature Phase-Shift Keyed (QPSK) signals used in the 802.11b standard. While future versions may include OFDM demodulation capability, this analysis includes the feasibility of using Signalworks® in a lab environment to demonstrate and educate students on signal characteristics including wireless communication signals.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGC	Automatic gain control
BPSK	Binary Phase-Shift Keyed
EW	Electronic Warfare
FSK	Frequency Shift Keyed
GMSK	Gaussian=Minimum Shift Keyed
LRS	Linear Recursive Sequence
MB/s	Megabits per second
MSK	Minimum-Shift Keyed
OFDM	Orthogonal Frequency Division Multiplexed
PSK	Phase-Shift Keyed
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keyed
RF	Radio Frequency
RFID	Radio Frequency Identification
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network

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ACKNOWLEDGMENTS

I thank my wife, children, and extended family for enduring countless hours of my absence while I was completing this project. They are the foundation of my success in the Navy and are most deserving of recognition. Their love and support through this and previous tours is the wind in my sails. I also thank Professor Tri Ha for his determination and guidance as my advisor. His background in signals and signal theory is extensive, and has proven critical to my research. Additionally, I thank Professor Vicente Garcia, whom I sought out as a fellow Cryptologist in search of research assistance. Although retired, he is a staunch advocate for our community and continues to serve us well. The staff at Signami-DCS were outstanding in their support. I specifically wish to thank Mr. Terry Cutshaw, Mr. Jacob Rorick, and Mr. Gary Kenworthy for their guidance and technical assistance.

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I. INTRODUCTION

A. OVERVIEW OF SIGNALWORKS® SOFTWARE SUITE

The Signalworks® software package developed by Signami-DCS is a Windows or Linux based suite of software tools that incorporates complex algorithms to enable advanced signals analysis. When coupled to a digital input, Signalworks® offers all the advantages of typical analysis equipment such as digital oscilloscopes, spectrum analyzers, and demodulators, combined into a simple to use interface requiring no programming or coding. Input to Signalworks® is accomplished via prerecorded files or through a digitizing component directly input to the computer. Signalworks® is capable of processing a variety of signal formats including Phase-Shift Keyed (PSK), Quadrature Amplitude Modulation (QAM), Frequency-Shift Keyed (FSK), Minimum-Shift Keyed (MSK), and Gaussian Minimum-Shift Keyed (GMSK). Signalworks® can breakout carrier frequency, symbol rate, modulation type, bit encoding and framing, and conduct link analysis to determine bit error rate and causes for performance degradation. Signalworks® is designed to be installed and operated on a Windows or Linux portable computer with minimal processing and memory requirements.

The software suite is divided into three main applications: Preview, Demod, and SignalGen. Preview is the analyst's initial step to define basic parameters and apply filters to enable the demodulator to process the signal. Preview allows the analyst to set an arbitrary center frequency, bandwidth, or roll-off frequency. The carrier frequency can be determined within Preview through second, fourth, and eighth order algorithms. The baud rate is also defined with the Preview application. Once these basic parameters have been determined, the analyst can view the results within Preview through a variety of time and frequency displays. Demod is the Signalworks® demodulator and equalizer. Within Demod, the analyst can select the signal format, choosing from PSK, QAM, FSK, MSK, and GMSK. Equalization can be adjusted by selecting

line canceling, dispersion-direction, or direction-detection algorithms. The analyst can utilize Demod to conduct bit-level analysis such as decoding, remapping, and frame sync operations. As with Preview, Demod offers the analyst a variety of display options both in time and frequency domains. Data displayed can be raw, intermediate, or processed signal externals. Demod can process teleprinter traffic in real-time and produce text outputs.

SignalGen allows the user analyst to generate their own signals with bit files or linear recursive sequencing pseudo-random noise generators. Signals can be simulated with varying sample and modulation rates having raised cosine or root raised cosine pulse shapes. Simulations include adding noise with arbitrary noise signal-to-noise ratios. Bit level operations are available for encoding and remapping. Once signals are generated, they are saved in an output file for later use in Preview or Demod.

B. OBJECTIVE

The objective of this thesis was to document the procedures for generating various signal formats and then processing them using Signalworks® for use in lab environments. While Signalworks® cannot yet demodulate Orthogonal Frequency Division Multiplexed (OFDM) signals used in wireless communications, it already offers considerable ability to process a variety of complex signals. An additional part of this project is to provide a feasibility study on whether Signalworks® is a viable platform to use in student labs to demonstrate signal characteristics, including wireless communication signals such as the 802.16 IEEE standard of signals.

C. THESIS ORGANIZATION

This thesis details how a user would build a signal and then process it to measure various parameters and determine the modulation within the Signalworks® software suite. The intended use of this detailed procedure is to include it as part of a class and lab curriculum. The thesis is organized into the following chapters:

Chapter II focuses on Phase-shift keyed signals. An initial overview of PSK signals and their typical applications is followed by a detailed systematic procedure from building a simulated PSK signal to inputting this simulated signal into Signalworks® for processing.

Chapter III covers Quadrature Phase-shift keyed signals. An initial overview of PSK signals and their typical applications is followed by a detailed systematic procedure from building a simulated QPSK signal to inputting this simulated signal into Signalworks® for processing.

Chapter IV contains information on Quadrature Amplitude Modulated signals to include 8, 16, and 64 State QAM signal formats. An initial overview of QAM signals and their typical applications is followed by a detailed systematic procedure from building a simulated QAM signal to inputting this simulated signal into Signalworks® for processing.

Chapter V focuses on wireless communication signals. Although Signalworks® has limited capability to process wireless communication signals, it allows signals to be viewed even if demodulation is not possible. .A general procedure for future use also is defined.

Chapter VI provides conclusions and recommendations.

This chapter provided background to the Signalworks® software suite and justification for the need of this project.

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II. PHASE-SHIFT KEYED SIGNAL ANALYSIS

A. OVERVIEW OF PHASE-SHIFT KEYED SIGNALS

1. Signal Characteristics

Phase-shift keying (PSK) is a product of the space program. PSK is a digital modulation technique that transmits data by changing the phase of the carrier frequency. The mathematical expression used for PSK is

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos[\omega_0 t + \phi_i] \quad \begin{array}{l} 0 \le t \le T \\ i = 1, \ldots, M \end{array}$$

The phase term ϕ_i will have M discrete values (Sklar 1079). The receiver in a phase-modulated system must have a reference oscillator to compare the incoming signal and determine if it is in-phase or if not, determine the relative phase compared to the reference. This section focuses on a binary signal having two transmitted phases, 180° apart. In binary phase-shift keyed (BPSK) signals, the frequency waveform utilizes one phase to convey a one and another phase to convey a zero as depicted in the diagram below (Sklar 1079).

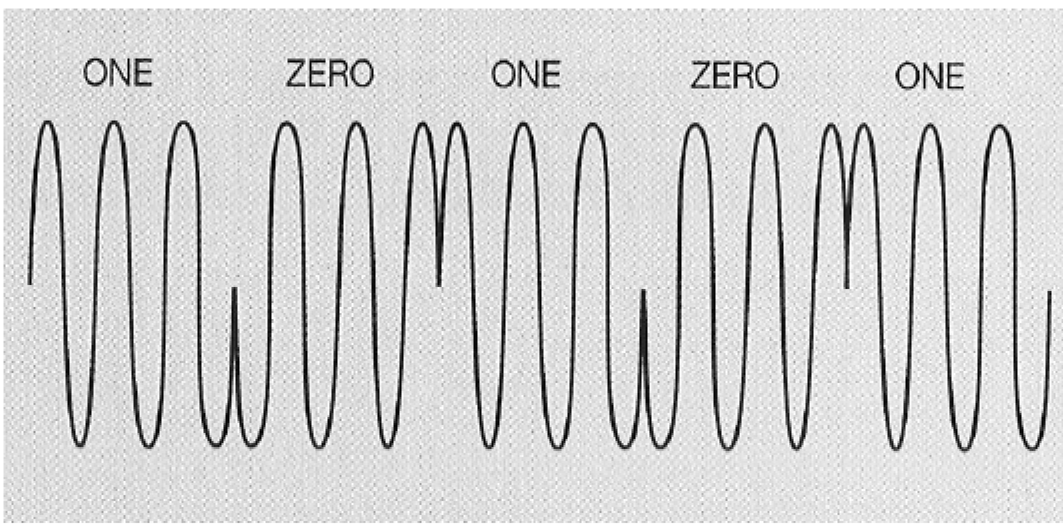


Figure 1. BPSK waveform

On a polar plot, a BPSK signal is depicted as vectors, with the vector length corresponding to the signal amplitude and the vector direction

corresponding to the phase relative to each signal in the set. In a BPSK, $M = 2$ so there are two vectors separated by 180° on the plot. The diagram below depicts a BPSK polar plot.

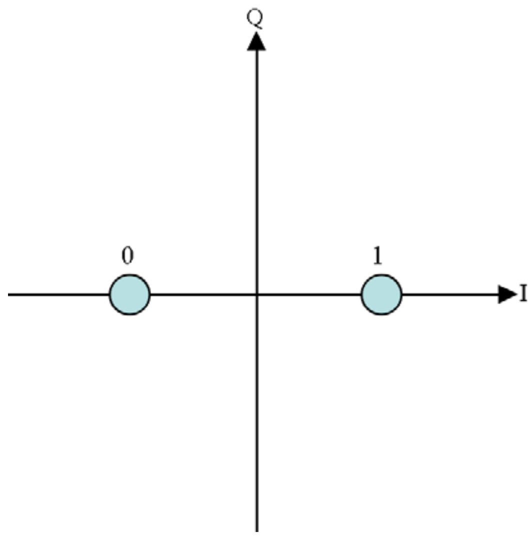


Figure 2. BPSK polar plot

2. Applications

PSK modulation is relatively simple in theory and operation. Because of this simplicity, it is widely used in a variety of applications. As mentioned previously, BPSK was first utilized in space applications. Its use was prominent in early digital broadcast satellite television systems, mainly in low-power satellite applications (Van der Wal and Montreuil 30-41). The simplicity of a PSK signal makes it an ideal modulation technique for low-cost passive transmitters such as Radio Frequency Identification (RFID) devices. RFID implementations range from asset tracking to credit cards to biometric passports. The basic IEEE 802.11b standard utilizes BPSK modulation, although only for slow data rate systems.

B. GENERATING TEST SIGNAL WITH SIGNALGEN

1. Procedural Guidance

This portion of the thesis begins the systematic procedures defining how to use the signal generation capabilities of Signalworks® with BPSK signals. To create and save signals within Signalworks®, the SignalGen application will be used. The following steps detail how to create a BPSK signal.

2. Creating a BPSK Signal using the Signalworks® SignalGen Application

To open SignalGen with default parameter settings, hold SHIFT while double clicking the SignalGen icon, if installed on the desktop, or select "All Programs>Signalworks>SignalGen." The first window that appears allows users to recall normal parameter settings, user defined settings, or default settings. Select "Cancel" to use default settings.

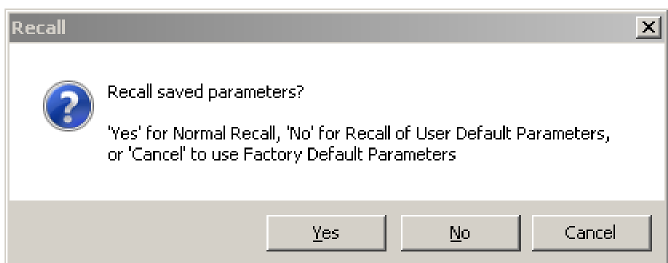


Figure 3. Recall default parameters window

Close the "Tip of the Day." The SignalGen window is now displayed. Click on the "Bit Operations" button. A new window pops up showing various tool palette input operations. For now, drag and drop the "LRS Encode" tool into the right-hand side of the window in the "Applied Operations" space. Click "OK."

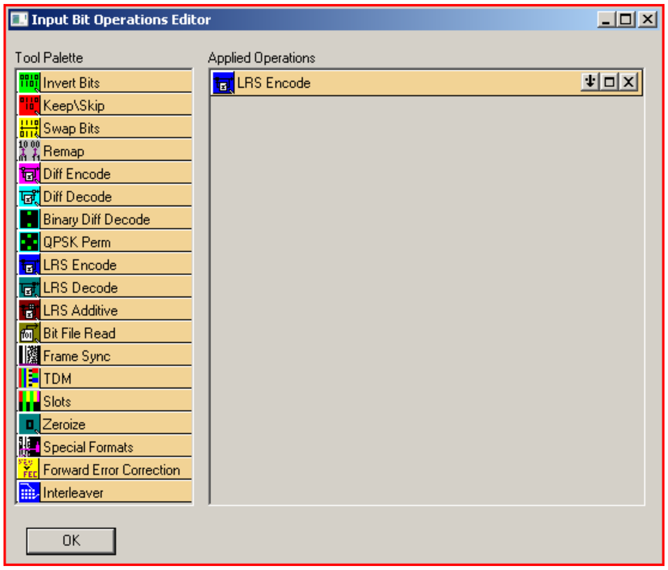


Figure 4. Input bit operations editor

Click on the “Signal” button underneath the baseband operations label in the SignalGen window.

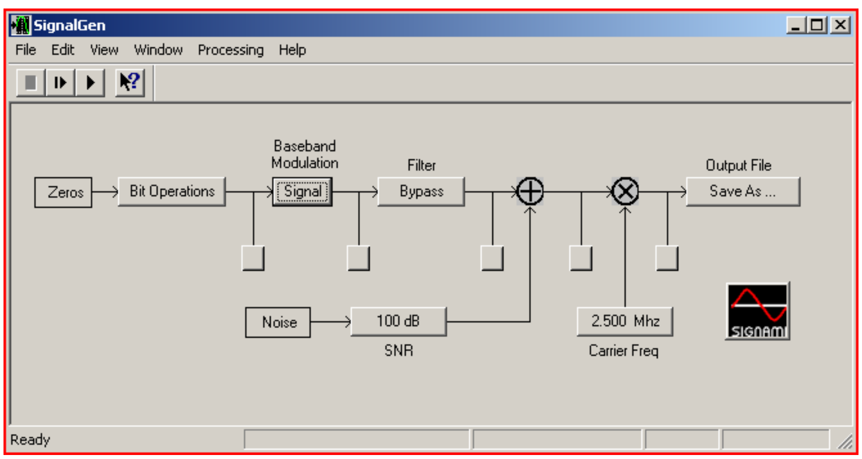


Figure 5. SignalGen for BPSK procedures

The SignalGen Modulation window pops up. Select “PSK” on the left hand side of the window.

Before closing this window, notice the pulse shaping pull down menu. The pulse shaping default is raised-cosine with beta equal to one. Pulse shaping is

used to achieve bandwidth reduction with respect to a rectangular pulse. The raised-cosine filter is the most popular pulse shape. The frequency response can be expressed as

$$H(f)=\begin{cases} 1, & |f| < 2W_0 - W \\ \cos^2\left(\dfrac{\pi}{4}\dfrac{|f|+W-2W_0}{W-W_0}\right), & 2W_0 - W < |f| < W \\ 0, & |f| > W \end{cases}$$

W is the absolute bandwidth and $W_0 = 1/2T$ is the Nyquist bandwidth for the rectangular spectrum and the half-amplitude point for the raised-cosine spectrum. The difference $W - W_0$ is excess bandwidth or that which is beyond the Nyquist minimum. Roll-off factor, defined to be $r = (W - W_0)/W_0$ where $0 \le r \le 1$, is the excess bandwidth divided by the filter −6dB bandwidth. The roll-off r specifies the required excess bandwidth as a fraction of W_0 and characterizes the steepness of the filter roll off. When $r = 1$, the required excess bandwidth is 100% and the tails of the pulse are quite small. This produces a symbol rate of R_S symbols per second using a bandwidth of R_S hertz, which is twice the Nyquist minimum bandwidth (Sklar 1079). The following figures show the difference in the pulse shape if the roll-off factor (β) is set to zero, one-half, or one.

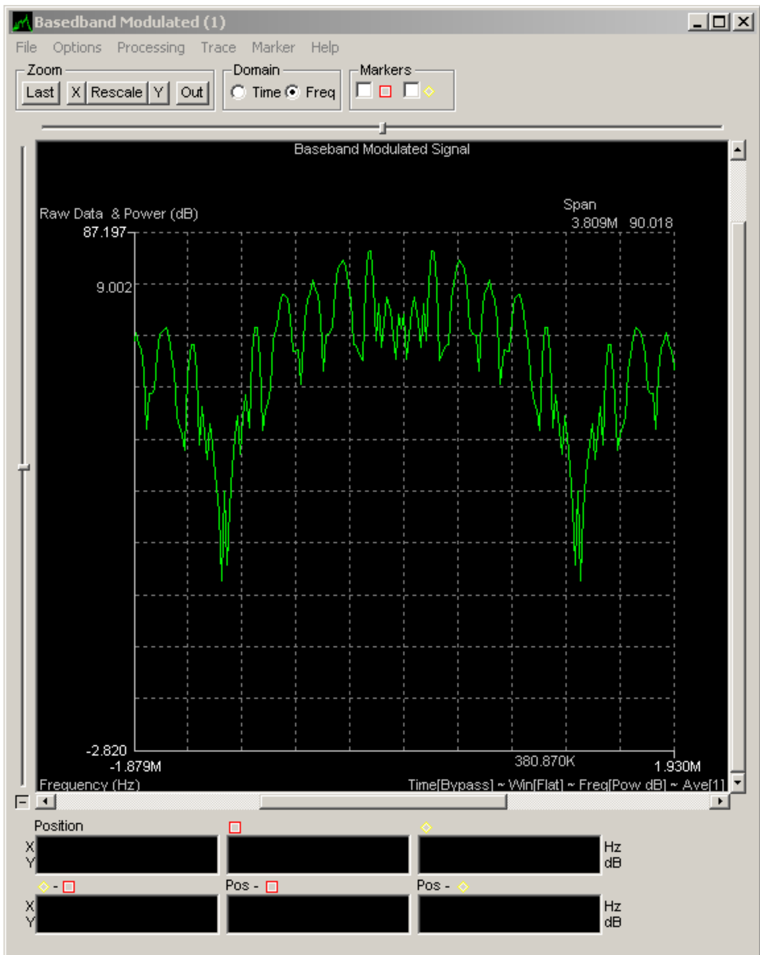


Figure 6. Raised cosine, $\beta = 0$ (Nyquist minimum bandwidth)

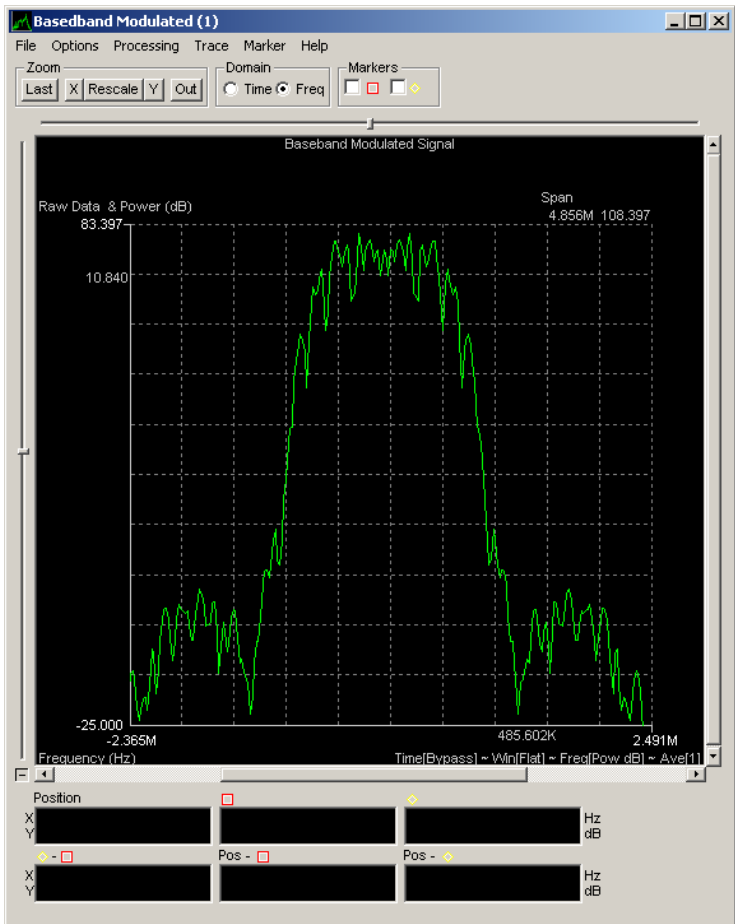


Figure 7. Raised cosine, $\beta = .5$

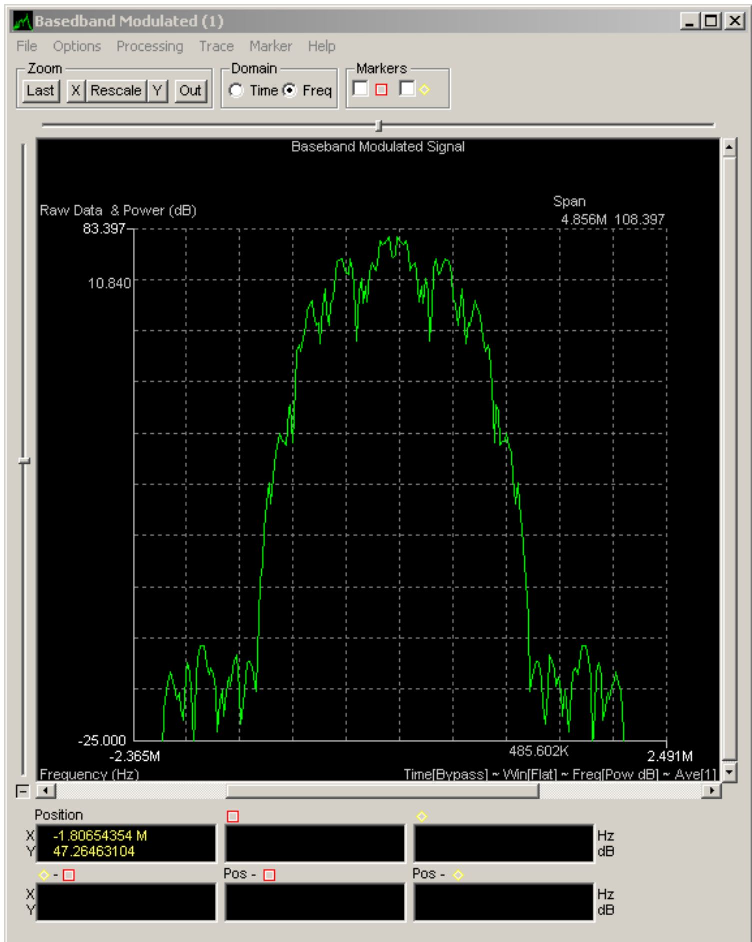


Figure 8. Raised cosine, $\beta = 1$

All other settings will remain the same and should be the same as the default settings shown below. Click "Close."

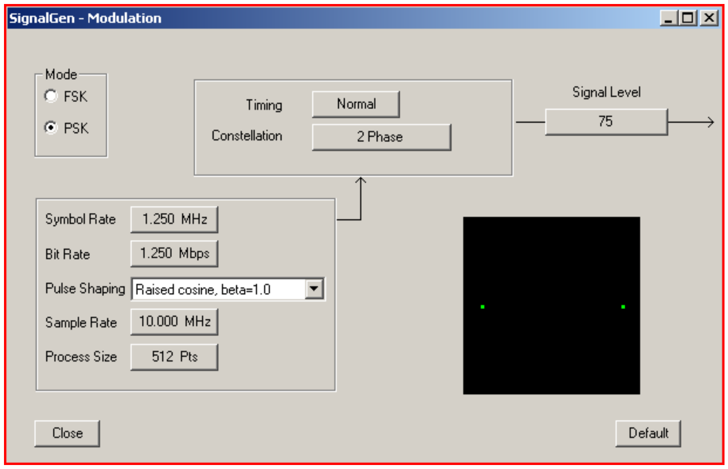


Figure 9. SignalGen modulation window for BPSK

We will now change the carrier frequency to 1.700MHz. In the SignalGen window, select the “Carrier Frequency” button on the lower left.

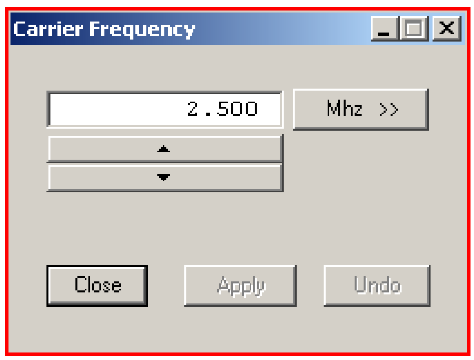


Figure 10. Carrier frequency default

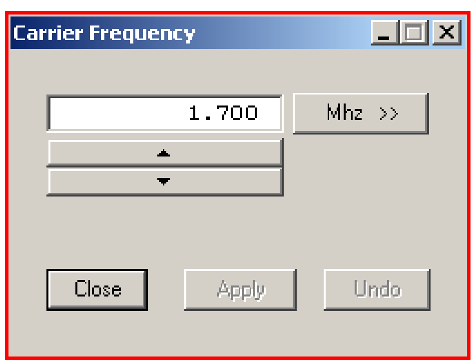


Figure 11. Carrier frequency set to 1700 KHz

Move the mouse over the arrow buttons directly under the column display and change the entry from 2.500 to 1.700. Click “Close.”

Now the signal is ready to be viewed on a display prior to saving it for further analysis. The unlabeled boxes in the SignalGen window are for opening display plots. Select the display that comes after the baseband modulation box.

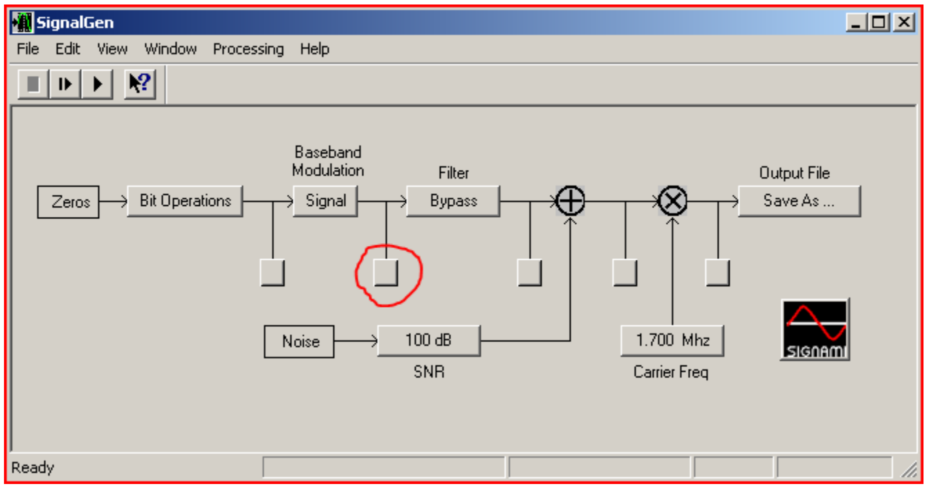
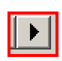


Figure 12. SignalGen test point at Baseband Modulation output

This will open up a blank Baseband Modulated display similar to an oscilloscope. With both the SignalGen and the Baseband Modulated windows within view, select the “play” button  at the top left of the SignalGen window. The display should now show a PSK signal like the one below.

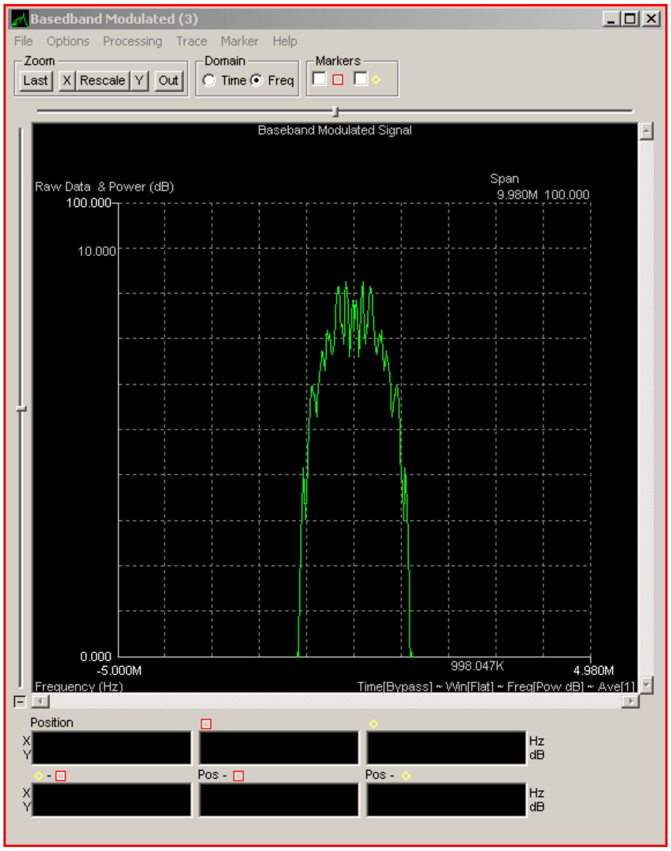


Figure 13. BPSK Baseband Modulated test point display

Let the signal continue to play and select the "Save as…" button underneath the Output File label on the SignalGen window. Select the desired directory where you would like to store this custom file and ensure the extension is ."byt." Name the file and select "Save." When the save is complete, you can stop playing the PSK signal you just created. The next step is to open Preview and begin doing the analysis on this signal. Close the SignalGen window.

C. INITIAL ANALYSIS WITH PREVIEW

1. Procedural Guidance

A test signal has just been created using SignalGen. Now that signal will be analyzed using the Preview application within Signalworks®. The Preview application allows us to measure some basic parameters and prepare the signal for further analysis using the Demod application.

2. Initial Analysis using the Signalworks® Preview Application

Open the Preview application in the same manner as you did with SignalGen. Hold the shift key and double click the Preview icon if installed on the desktop or select “All Programs>Signalworks>SignalGen.” Again, select “Cancel” to resort to the default settings. Close the “Tip of the Day.”

First, the PSK file saved in SignalGen must be loaded into the Preview application. Select the box labeled “File.dll” under Input.

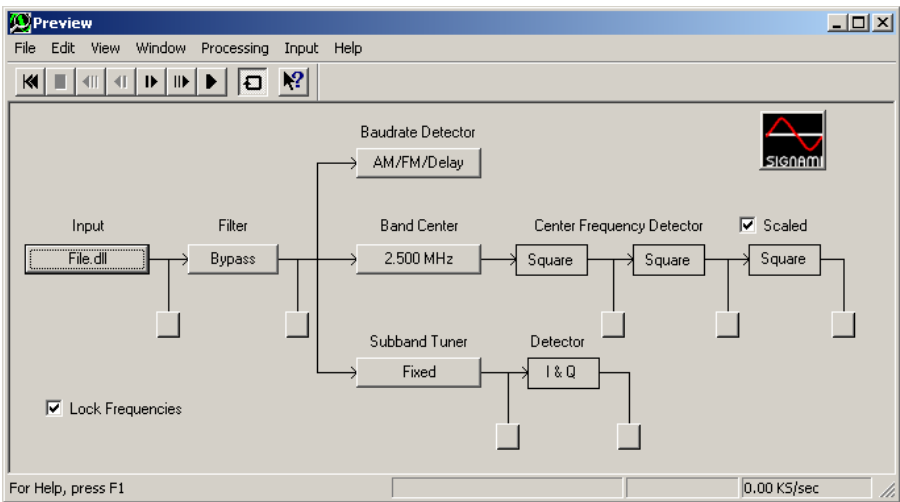


Figure 14. BPSK Preview window

Select the “Select file” button on the left side of the window labeled File Name. Navigate to the directory where the PSK file was saved and select it. The window below shows the PSK file “psk1700m.byt” selected. Click “Close” on this window.

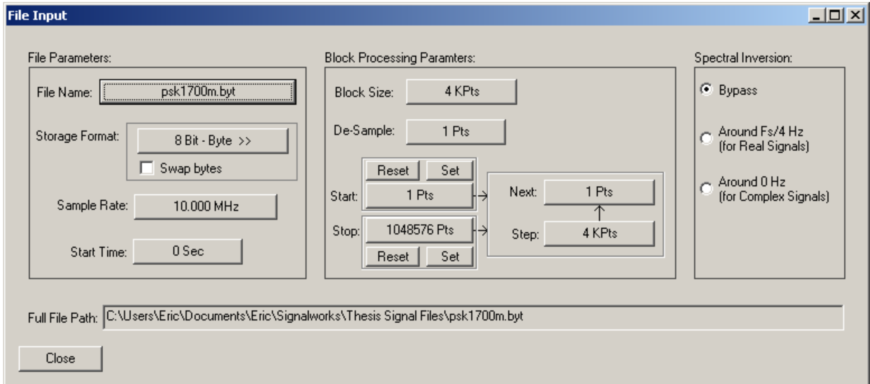
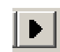
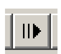


Figure 15. BPSK File input selection

The PSK signal created earlier is now queued and ready to play and analyze with the Preview application. Select either the normal play  or the slow motion play  button at the top of the Preview window. Select the display button after the Input to view the PSK signal.

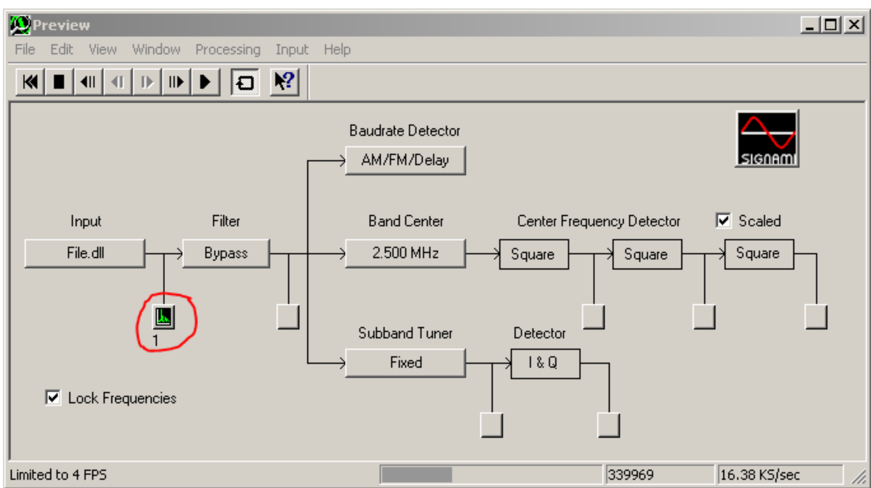


Figure 16. BPSK Preview test point at file input

The signal should be displayed in the “Input” window and will appear like the one below.

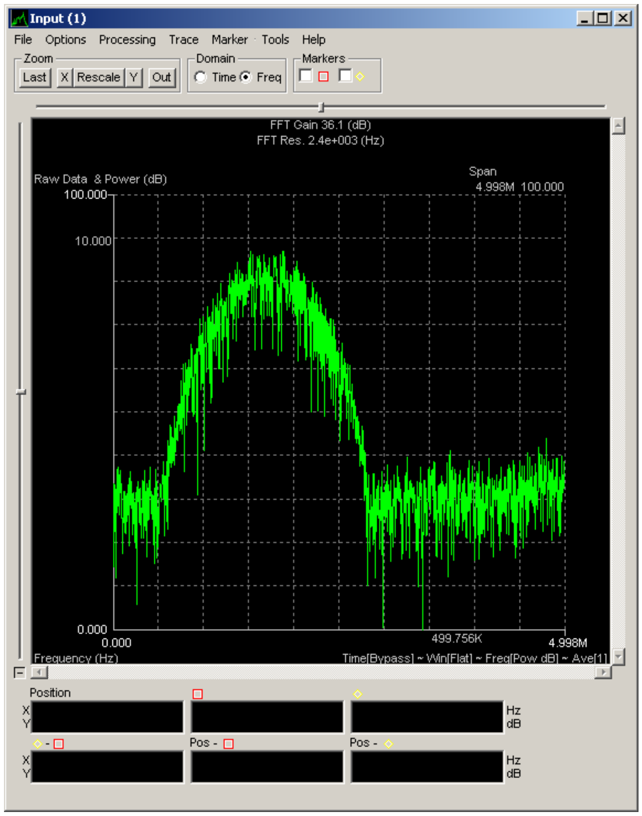


Figure 17. BPSK Preview test point display

The first step in measuring the center frequency of this PSK is to set the approximate band center. In the Input display, which shows the PSK in frequency (x-axis) and amplitude (y-axis), pull down the Tools menu from the top and select “Set band center.” Then move the cursor so that it is in the approximate middle of the PSK signal. Click on the display to set the band center. The band center setting that you selected is shown in the Preview window’s “Band Center” entry.

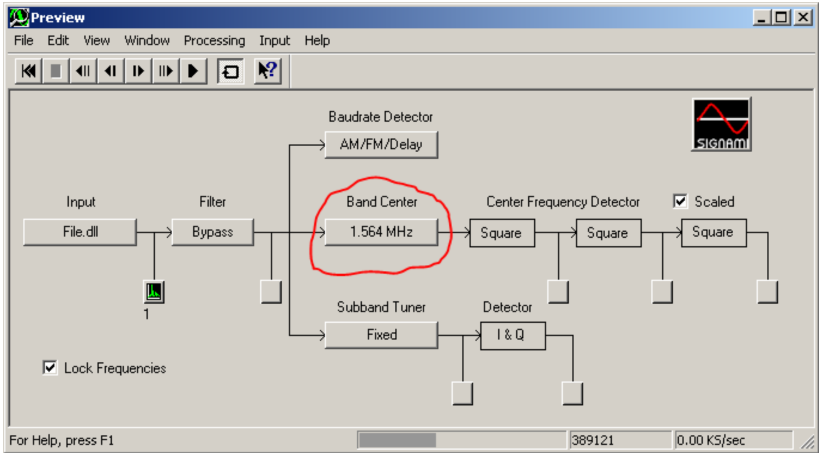


Figure 18. BPSK Preview band center specified

Open a test point display in the Center Frequency Detector portion of the Preview window after the first "Square" box. By squaring the frequency in a PSK signal, the center frequency will be revealed.

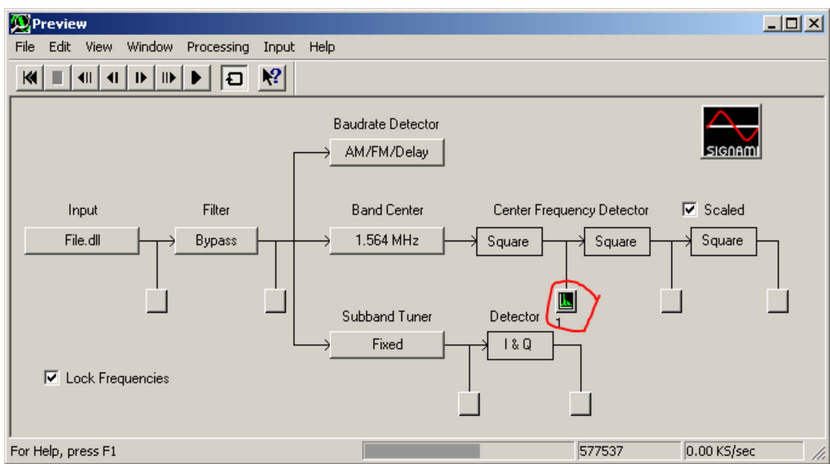


Figure 19. BPSK Preview test point at Center Freq. Detector

The display that opens is titled "CF^2(1)" which indicates you are looking at the center frequency squared. The display will show the PSK signal with a prominent spike in the center of the signal. Select the square marker at the top of the window. The marker should appear at the top of this spike and the frequency is reflected in the bottom of the window.

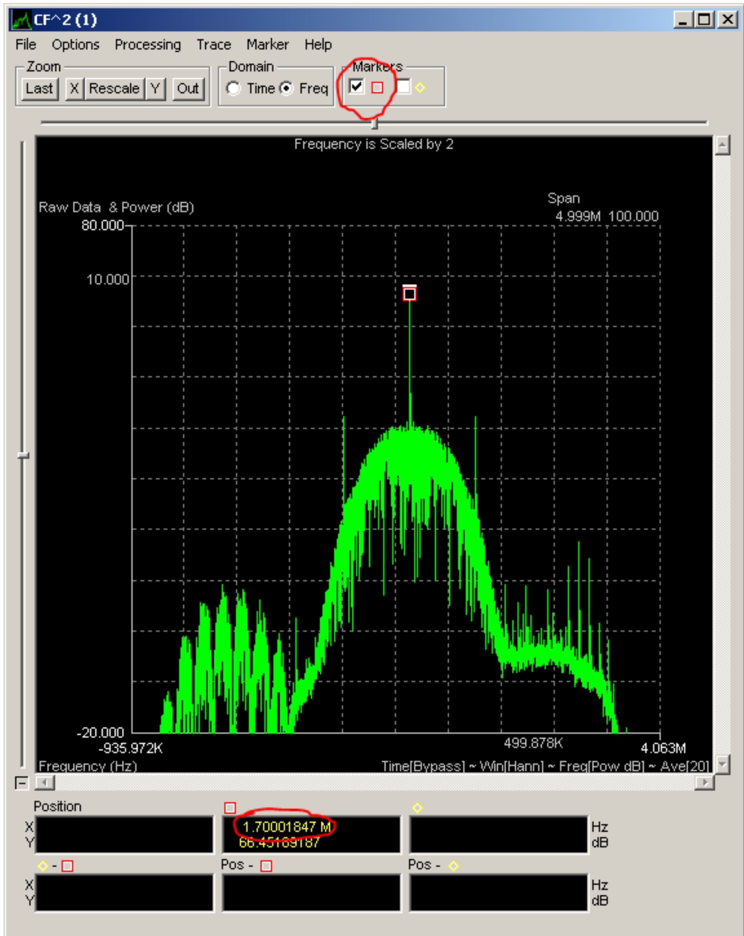


Figure 20. BPSK center frequency marker

The center frequency should be 1.7MHz, which corresponds to what was defined as the carrier frequency in SignalGen when creating this signal. Leave this window open.

Next, we will derive the symbol (baud) rate or keying rate. Assure the PSK signal sample is playing, in either full motion or slow motion, and then select the “AM/FM/Delay” button underneath the Baud rate label on the Preview window. A new window will open, select the AM Detector test point to bring up a new display.

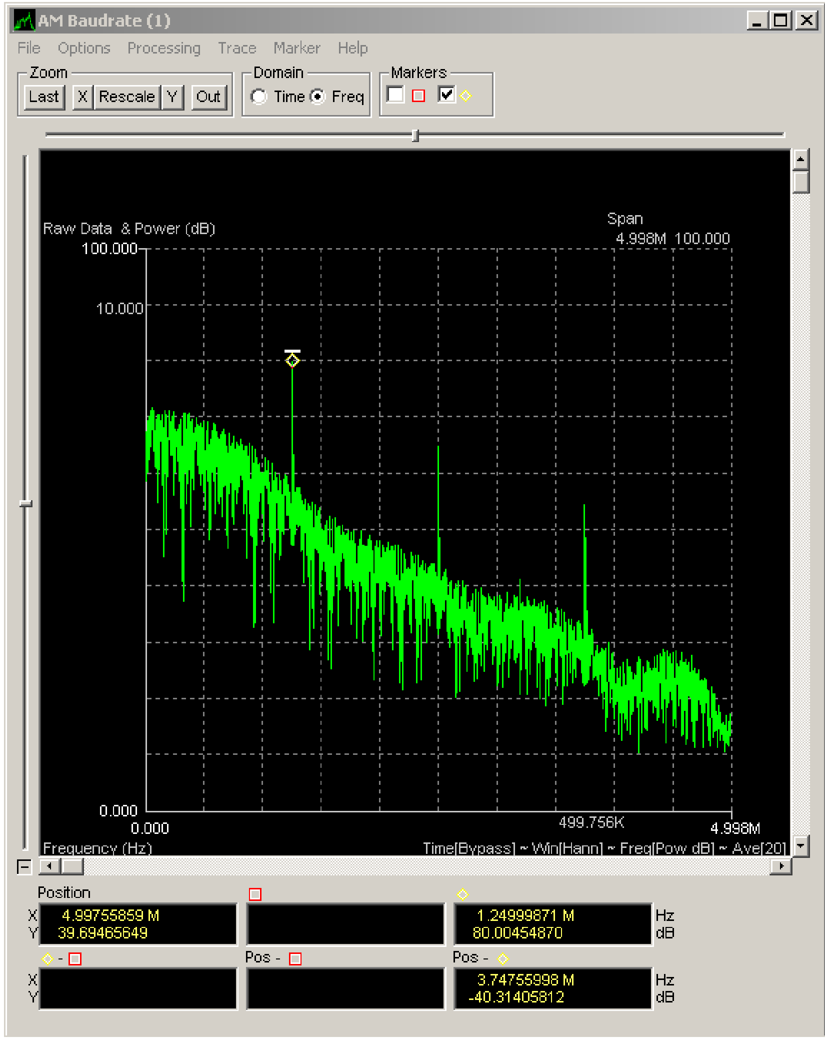


Figure 21. BPSK baud rate display

Select the other marker at the top of the window and assure the marker is placed on the left most spike within the AM Baud rate display. You can drag the marker to the left most spike if it is not placed there automatically. The measurement at the bottom of the display should read “1.25MHz” which is the baud rate specified when building this signal file in SignalGen. Leave this window open.

The center frequency (carrier) has been measured and the symbol rate, which is also the bit rate in this case, has been measured.

Ensure that the carrier frequency and symbol rate displays are active with their respective markers indicating the measured parameters. Select the "File" pull-down menu and select "Export / Save for Demod." The window that appears shows all active display parameters.

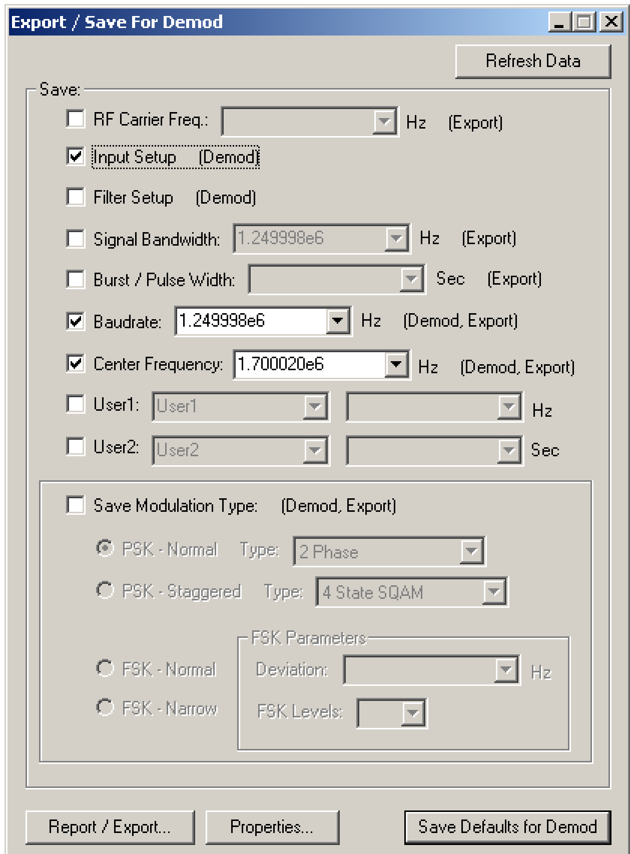


Figure 22.   BPSK export/save for Demod

Select "Save Defaults for Demod" at the bottom of the window. This saves your measured parameters for the Demod.

D. ADDITIONAL ANALYSIS WITH DEMOD

1. Procedural Guidance

Demod is the advanced analysis feature of Signalworks®. It can demodulate signals and perform bit-level analysis. Demod will be used to define the modulation of the signal created earlier using SignalGen, which was initially processed using Preview.

2. Advanced Analysis with Demod

Open Demod either by double clicking on the icon or by selecting it from the Program menu. Do not hold shift. Demod will open with the parameters from Preview already loaded.

Open the test point after the mixer.

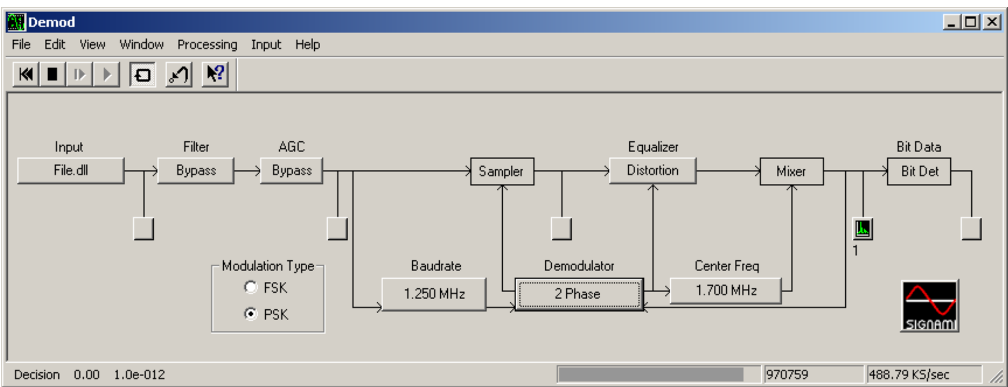


Figure 23. BPSK Demod test point at mixer output

The test point display should appear similar to Figure 24 shown below with annotations to help explain the varying phase shifts and axis labels. Notice there are two groupings along the I axis, which appear as small dots on the display. The display is a polar plot of a binary phased signal. These dots are two different phase symbols, 180° apart, which represent a 1 and a 0. Although the graphic is static, viewing the display on the computer will show that there are variations on the grouped plot as each symbol is transmitted.

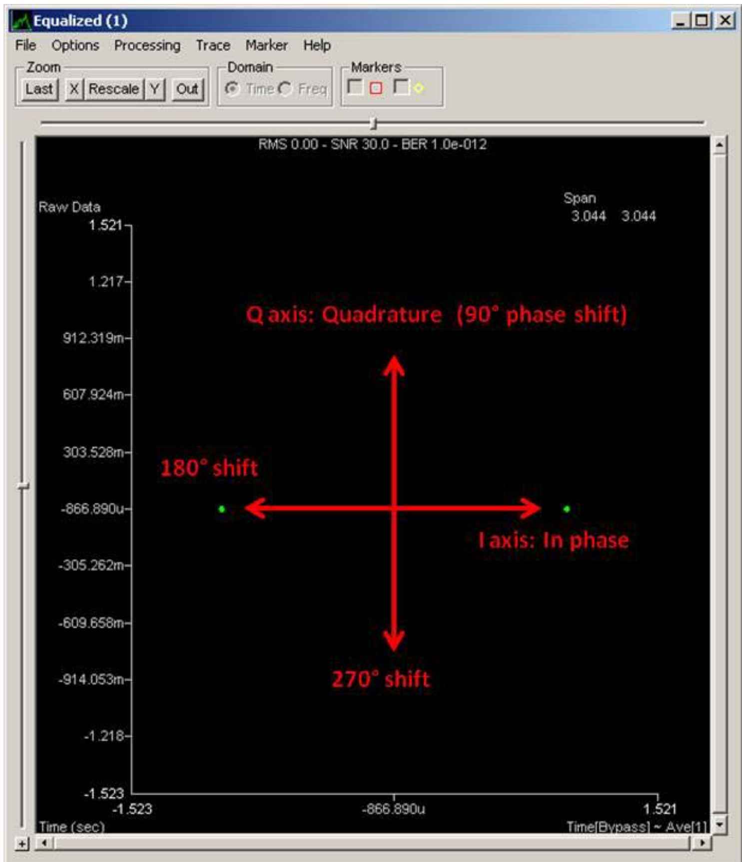


Figure 24. BPSK Demod test point display

If the modulation was not correctly defined, the two groupings would not be locked into the position shown in Figure 24. Viewing this on the computer with the incorrect modulation technique defined would result in the appearance of a circle as the groupings spin about the center of the plot. The display in Figure 24 is the desired presentation and shows that the modulation selected is the signal's actual modulation. This signal is defined as a 2-State or Binary Phase-Shift Keyed signal.

E. BPSK ANALYSIS RESULTS

This completes the BPSK portion of the project. In this section, Signalworks® was used to generate a BPSK signal using SignalGen and then analyze that signal using Preview and Demod. In a real-world situation, the signal would be input to Signalworks® via a digitizer connected to the host

computer. The user would not know the type of signal, and thus would begin the process of changing the modulation until the display at the end of the Demod procedure was achieved. Once the carrier frequency and the baud rate are set, the only change necessary is to the modulation technique. In a real-world scenario, additional noise may also be present requiring the need for filters to isolate the signal.

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III. QUADRATURE PHASE-SHIFT KEYED SIGNAL ANALYSIS

A. OVERVIEW OF QUADRATURE PHASE-SHIFT KEYED SIGNALS

1. Signal Characteristics

The rise of digital communications has resulted in a growing demand for increased efficiency with regard to channel bandwidth utilization. The concept of phase shifting a sinusoidal carrier to convey data can be expanded from the binary or two-phase model. A more efficient quadriphase or quaternary shift is possible where the phase shift occurs at four equally spaced values such as $\pi/4$, $3\pi/4$, $5\pi/4$, and $7\pi/4$. With four phases, a Quadrature Phase-Shift Keyed (QPSK) signal can encode two bits for every symbol, resulting in either doubling of the data rate of a BPSK at the same bandwidth or halving the bandwidth at the same date rate of a BPSK.

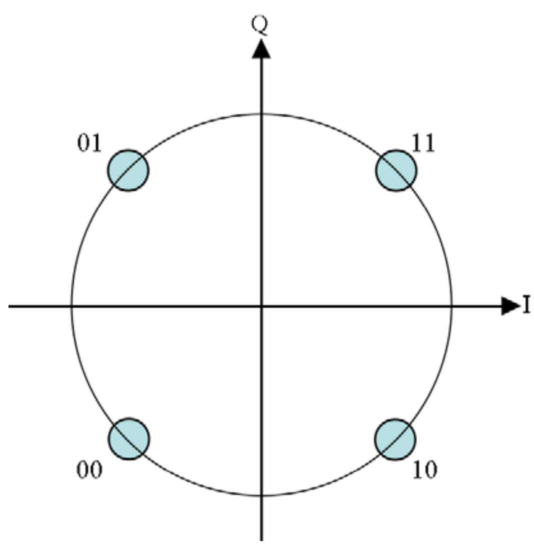


Figure 25. QPSK polar plot

Mathematically, a QPSK is represented as follows:

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos\left(\omega_0 t + (2i-1)\frac{\pi}{M} \right) \quad \begin{array}{l} 0 \le t \le T \\ i = 1,\ldots,M \end{array}$$

M is equal to four to reflect the four phase shifts used to represent the bit pairs. The parameter E represents the symbol energy, and T is the symbol time.

2. Applications

Similar to BPSK modulated signals, QPSK modulation was first developed for space applications, and eventually found its way into many types of communications systems where spectrum conservation is necessary. Today, more advanced signal modulation techniques dominate, but systems with limited spectrum still utilize QPSK formats. As more points are introduced to the constellation, the error rate increases. The balance is determined by the user, who dictates the desired throughput for a given spectrum and either accepts a certain level of error, or implements additional solutions to minimize error while sustaining a certain data rate.

B. GENERATING QPSK TEST SIGNAL WITH SIGNALGEN

1. Procedural Guidance

This portion of the thesis begins the systematic procedures defining how to use the signal generation capabilities of Signalworks® with QPSK signals. To create and save signals within Signalworks®, the SignalGen application will be used. The following steps detail how to create a QPSK signal.

2. Creating a QPSK Signal using the Signalworks® SignalGen Application

To open SignalGen with default parameter settings, hold SHIFT while double clicking the SignalGen icon if installed on the desktop or select "All Programs>Signalworks>SignalGen." The first window that appears allows

users to recall normal parameter settings, user defined settings, or default settings. Select “Cancel” to use default settings.

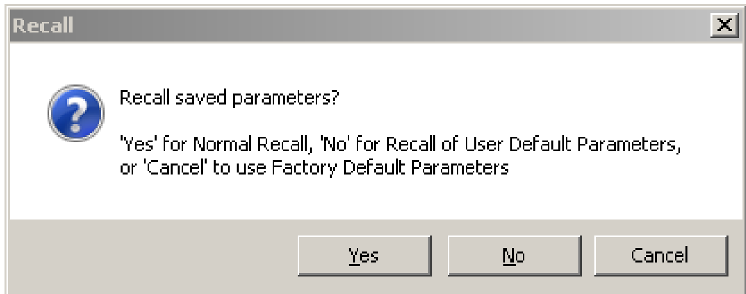


Figure 26. QPSK Recall default parameters window

Close the “Tip of the Day.” The SignalGen window is now displayed. Click on the “Bit Operations” button. A new window pops up showing various tool palette input operations. Drag and drop the “QPSK Perm” and “LRS Encode” tools into the right-hand side of the window in the “Applied Operations” space. Click “OK.”

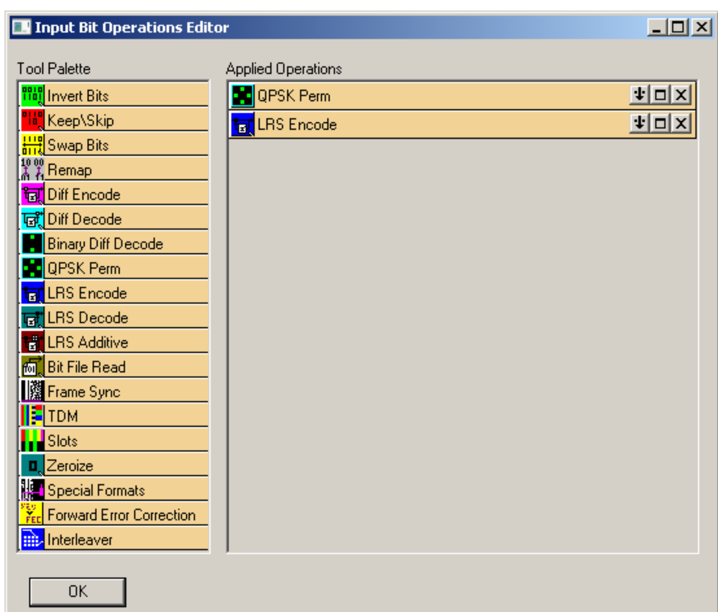


Figure 27. Input Bit Operations Editor

Click on the “Signal” button underneath the baseband operations label in the SignalGen window.

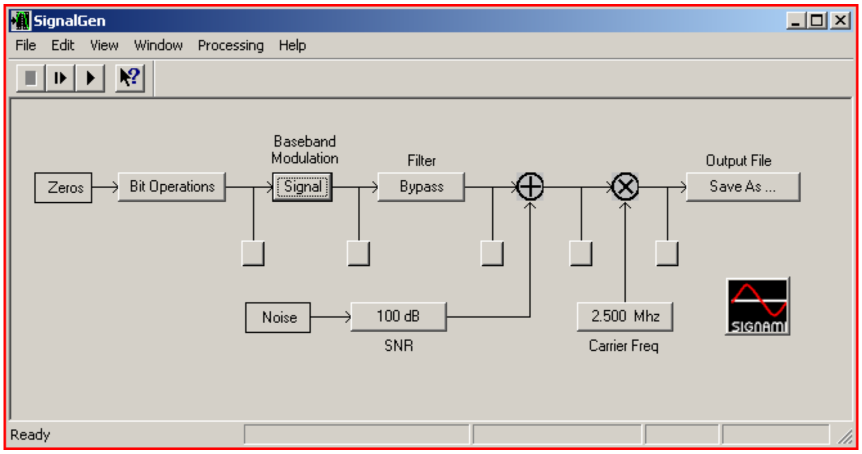


Figure 28. SignalGen for QPSK procedures

The SignalGen Modulation window pops up. Select "PSK" on the left hand side of the window. Select the "2 Phase" button next to the Constellation label and select "4 Phase." Next, select the "2.500 Mbps" button next to Bit Rate and change the bit rate to "3.400 Mbps." All other settings will remain the same and should be the same as the default settings shown below. Click "Close."

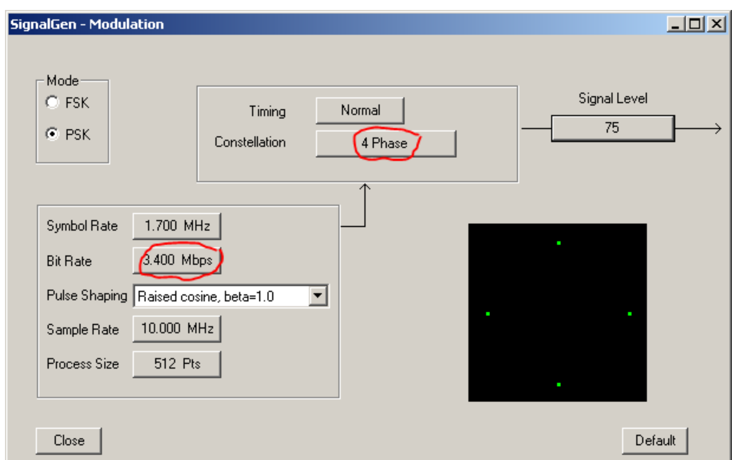


Figure 29. SignalGen Modulation window for QPSK

We will now change the carrier frequency to 3.000MHz. In the SignalGen window, select the "Carrier Frequency" button on the lower left. Move the mouse over the arrow buttons directly under the column display and change the entry from 2.500 to 3.000. Click "Close."

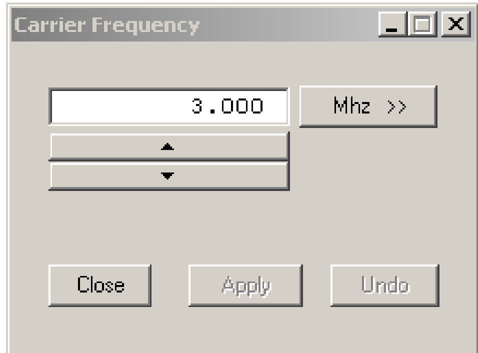


Figure 30. Carrier frequency set to 3000 KHz

Now the signal is ready to be viewed on a display prior to saving it for further analysis. The unlabeled boxes in the SignalGen window are for opening display plots. Select the test point display that comes after the Baseband Modulation box.

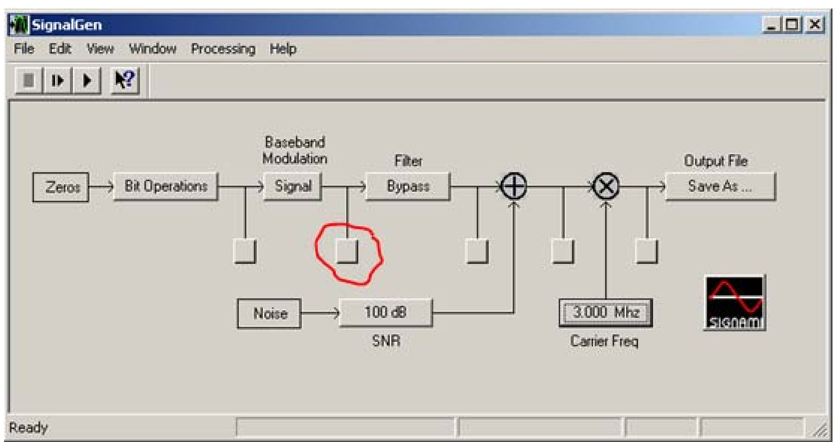


Figure 31. SignalGen test point at Baseband Modulation output

This will open up a blank Baseband Modulated display similar to an oscilloscope. With both the SignalGen and the Baseband Modulated windows within view, select the “play” button  at the top left of the SignalGen window. The display should now show a QPSK signal like the one below.

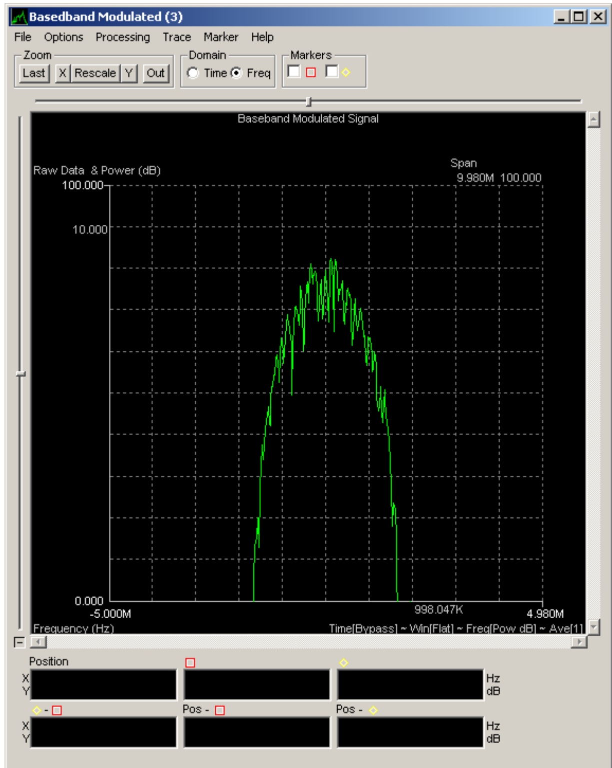


Figure 32. QPSK Baseband Modulation test point display

Let the signal continue to play and select the "Save as…" button underneath the Output File label on the SignalGen window. Select the desired directory where you would like to store this custom file and ensure the extension is "byt." Name the file and select "Save." When the save is complete, you can stop playing the PSK signal you just created. The next step is to open Preview and begin doing the analysis on this signal. Close the SignalGen window.

C. INITIAL ANALYSIS WITH PREVIEW

1. Procedural Guidance

A QPSK test signal has just been created using SignalGen. The signal is ready to be analyzed using the Preview application within Signalworks®. The Preview application allows us to measure some basic parameters and prepare the signal for further analysis using the Demod application.

2. Initial Analysis using the Signalworks® Preview Application

Open the Preview application in the same manner as you did with SignalGen. Hold the shift key and double click the Preview icon if installed on the desktop or select “All Programs>Signalworks>SignalGen.” Again, select “Cancel” to resort to the default settings. Close the “Tip of the Day.”

First, the QPSK file saved in SignalGen must be loaded into the Preview application. Select the box labeled “File.dll” under Input.

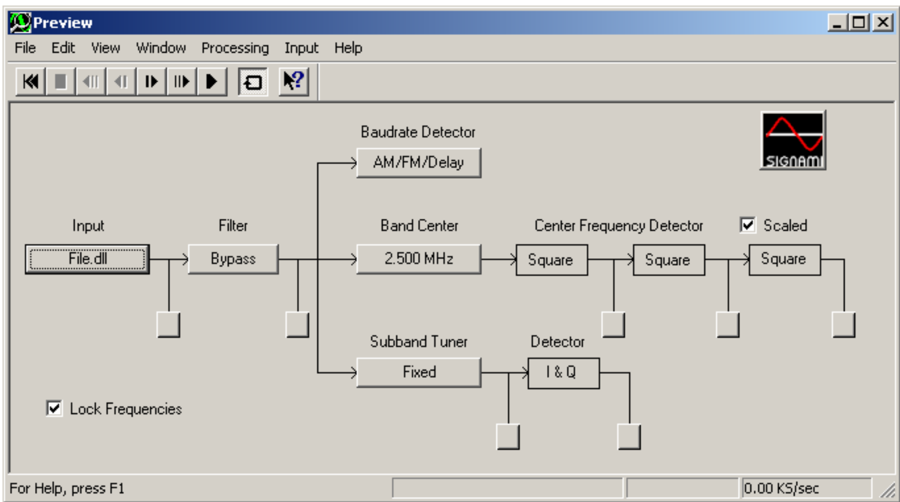


Figure 33. QPSK Preview window

Select the “Select file” button on the left side of the window labeled File Parameters. Navigate to the directory where the PSK file was saved, and select it. The window below shows the PSK file “qpsk3000m.byt” selected. Click “Close” on this window.

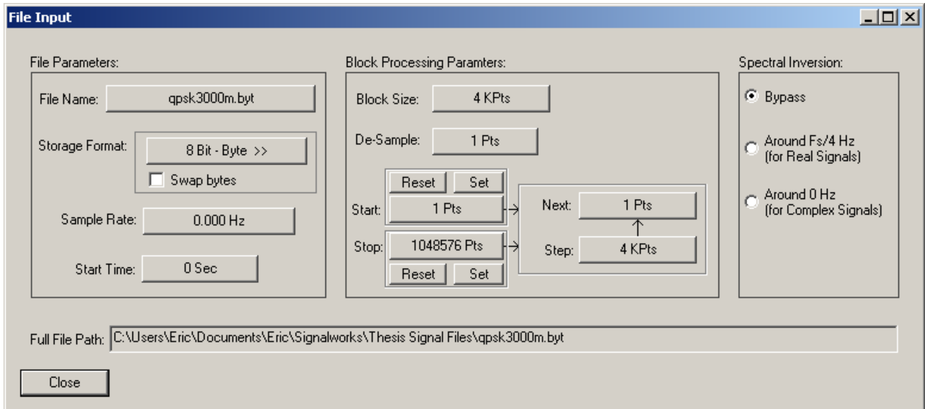


Figure 34. QPSK file input selection

The QPSK signal created earlier is now queued and ready to play and analyze with the Preview application. Select either the normal play  or the slow motion play  button at the top of the Preview window. Select the display button after the Input to view the QPSK signal.

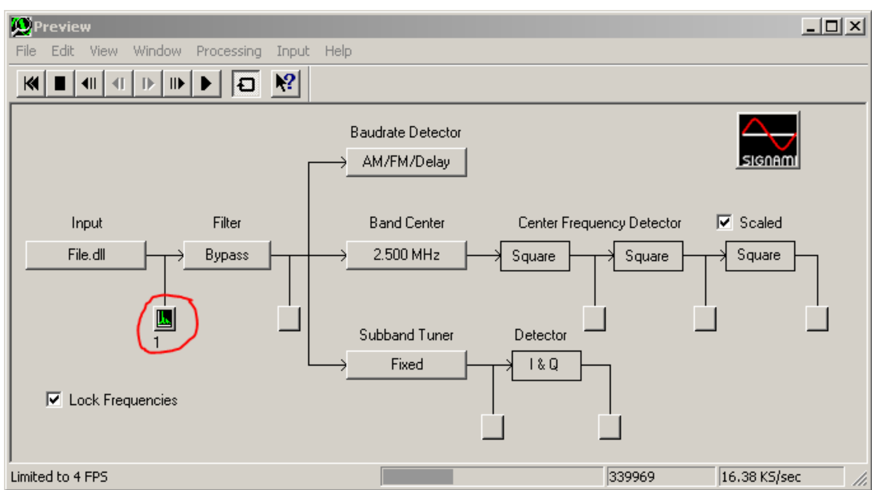


Figure 35. QPSK Preview test point at file input

The signal should be displayed in the “Input” window and will appear like the one below.

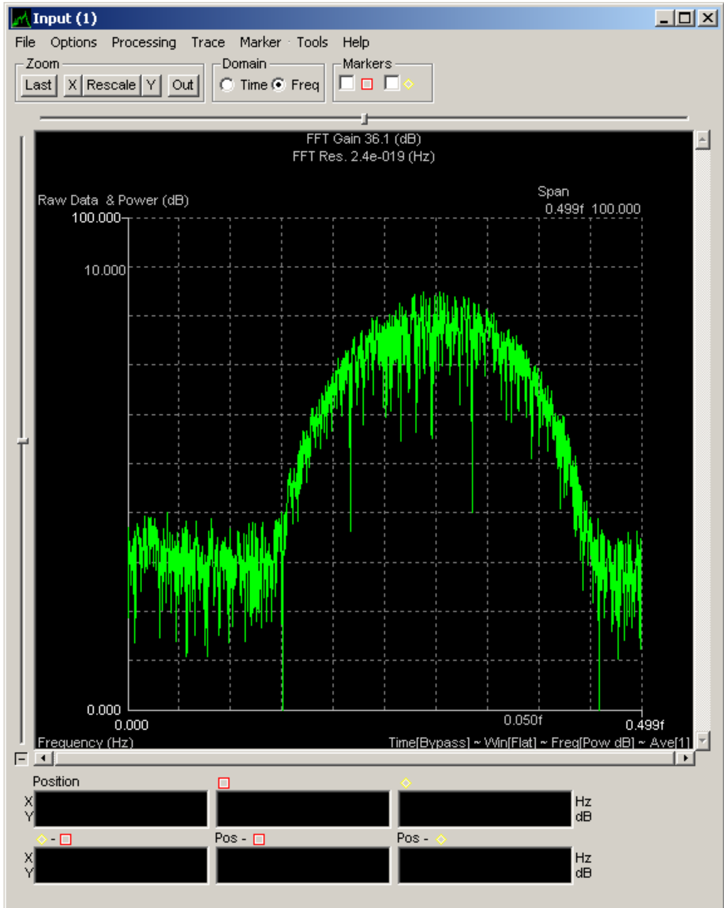


Figure 36. QPSK Preview test point display

The first step in measuring the center frequency of this QPSK is to set the approximate band center. In the Input display, which shows the QPSK in frequency (x-axis) and amplitude (y-axis), pull down the Tools menu from the top and select “Set band center.” Then move the cursor so that it is in the approximate middle of the QPSK signal. Click on the display to set the band center. The result is different compared to the PSK signal processed earlier. In this case, the band center changes to all zeroes.

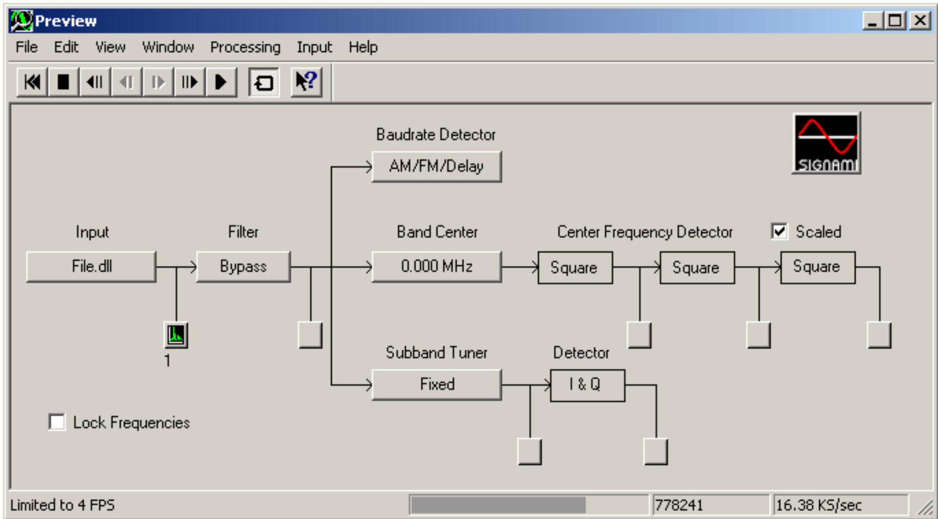


Figure 37. QPSK Preview band center

Open a test point display in the Center Frequency Detector portion of the Preview window after the first "Square" box. An open test point window is signified by the spectrum graphic that appears on the test point button. Notice that the display that opens does not reveal a center frequency spike. This is an indication that the signal of interest may not be a simple PSK. Close this display and open a test point display after the second Square block. By double squaring the frequency in a QPSK, the center frequency reveals itself.

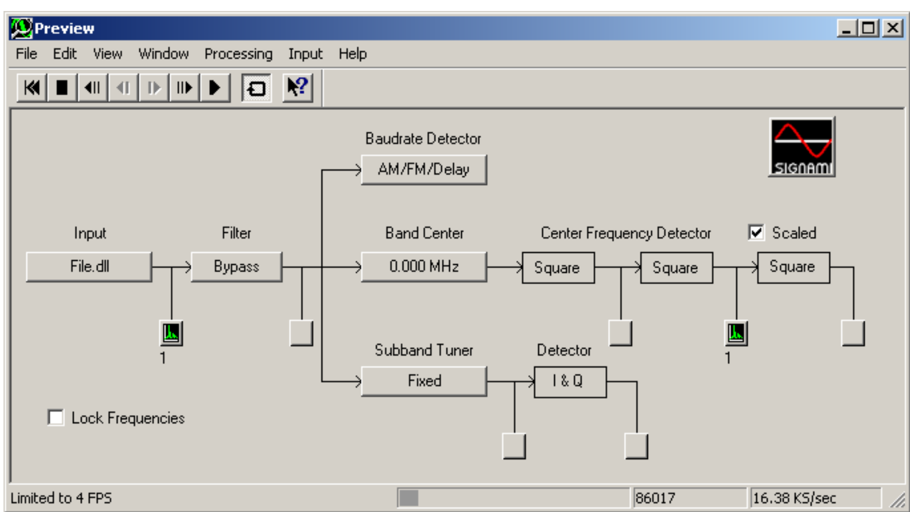


Figure 38. QPSK Preview test point at Center Frequency Detector

The display that opens is titled “CF^4(2)” which indicates you are looking at the center frequency double squared. The display will show the QPSK signal with a prominent spike in the center of the signal. Select the square marker at the top of the window. The marker should appear at the top of this spike and the frequency is reflected in the bottom of the window.

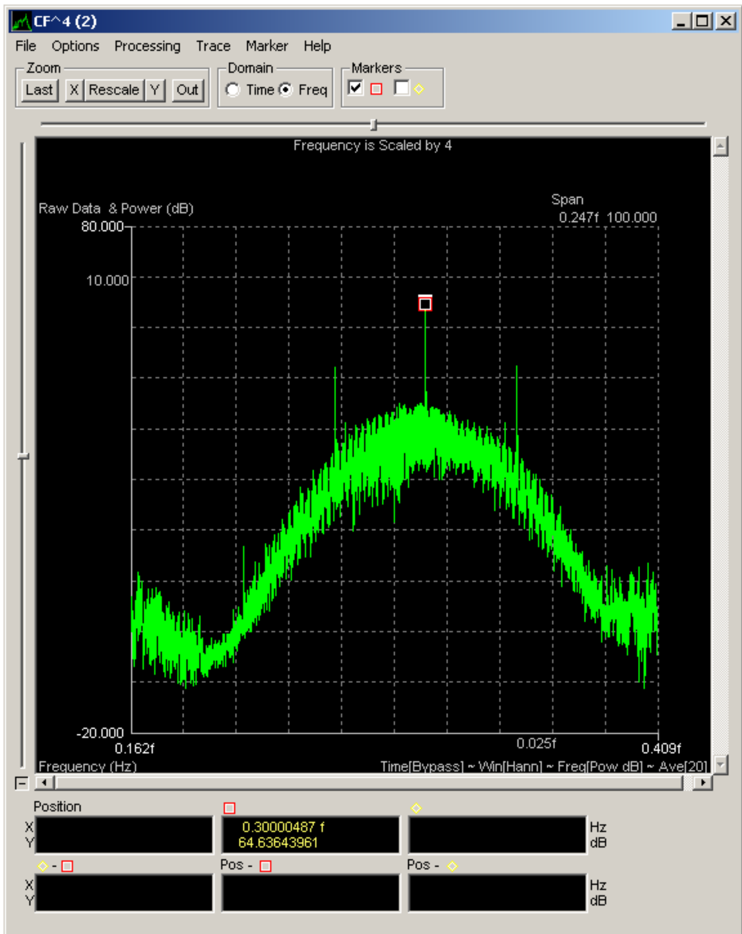


Figure 39. QPSK center frequency marker

The center frequency should be 3.0MHz, which corresponds to what was defined as the carrier frequency in SignalGen when creating this signal. Leave this window open.

Next, we will derive the symbol (baud) rate. Assure the QPSK signal sample is playing, in either full motion or slow motion, and then select the “AM/FM/Delay” button underneath the Baud rate label on the Preview window. A

new window will open, select the AM Detector test point to bring up a new display. Select the other marker at the top of the window and assure the marker is placed on the left most spike within the AM Baud rate display.

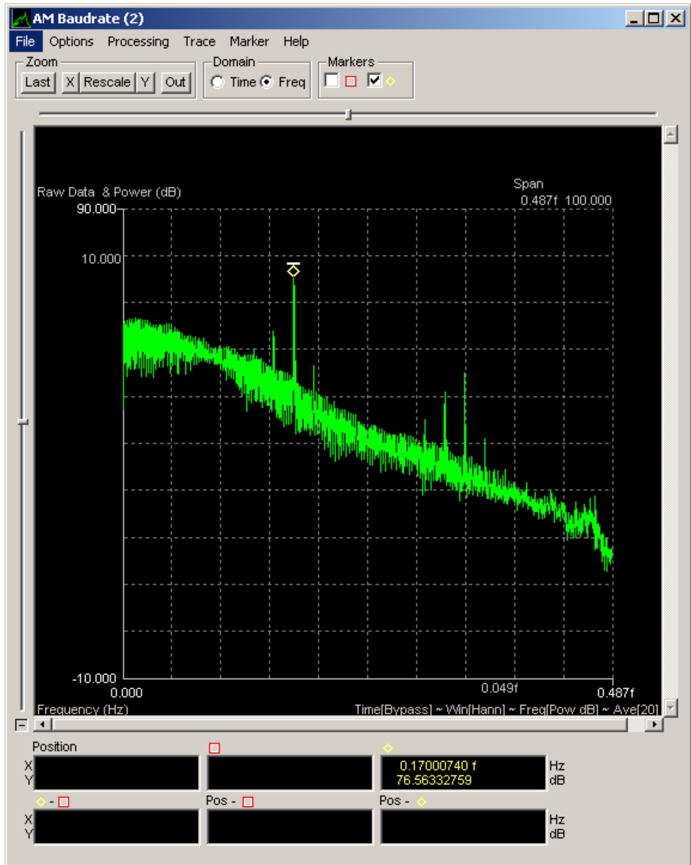


Figure 40. QPSK baud rate display

You can drag the marker to the left most spike if it is not placed there automatically. The measurement at the bottom of the display should read ”1700,” which is the symbol rate specified when building this signal file in SignalGen. The fact that the carrier frequency was revealed only when double squaring the center frequency means this PSK is a 4-phase signal instead of 2 phase. Bit rate, measured in bits per second, is twice the symbol rate for a QPSK signal because there are now twice as many positions, or phases, that can represent a symbol. Refer back to the QPSK polar plot in Figure 25 and notice that each position represents two bits, which are 00, 01, 10, and 11. A

binary plot allows only a 1 or 0 at each position. Symbol rate is measured in baud, or symbols per second. The measured symbol rate was 1.7 MBaud and when doubled results in a bit rate of 3.4 Mbit/s.

Ensure that the carrier frequency and symbol rate displays are active with their respective markers indicating the measured parameters. Select the “File” pull-down menu and select “Export / Save for Demod.” The window that appears shows all active display parameters.

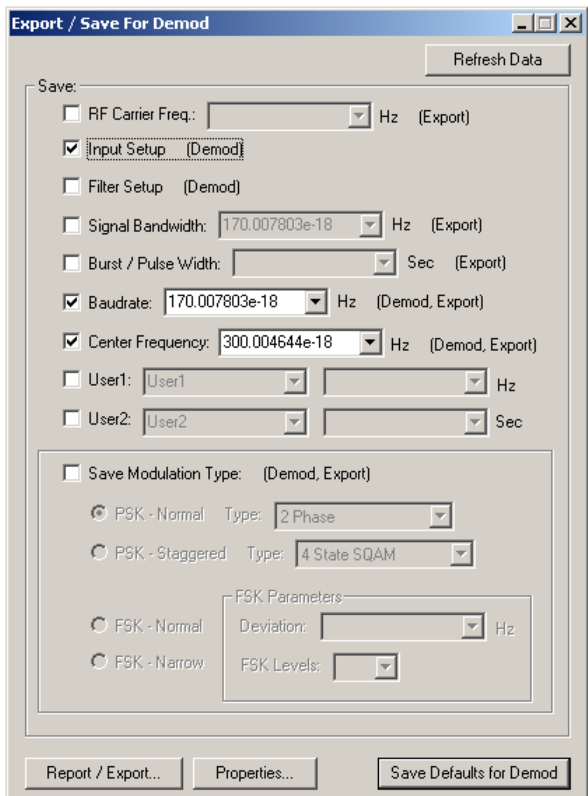


Figure 41. QPSK export/save for Demod

Select “Save Defaults for Demod” at the bottom of the window. This saves your measured parameters for the Demod.

D. ADDITIONAL ANALYSIS WITH DEMOD

1. Procedural Guidance

Demod is Signalworks'® advanced analysis application. It can demodulate signals and perform bit level analysis. Here, Demod will be used to define the modulation of the QPSK signal created earlier using SignalGen, which was initially processed using Preview.

2. Advanced Analysis with Signalworks'® Demod Application

Demod will be used to identify the type of signal that is being analyzed. Open Demod either by double clicking on the icon or by selecting it from the Program menu. Do not hold shift. Demod will open with the parameters from Preview already loaded.

Open the test point after the mixer.

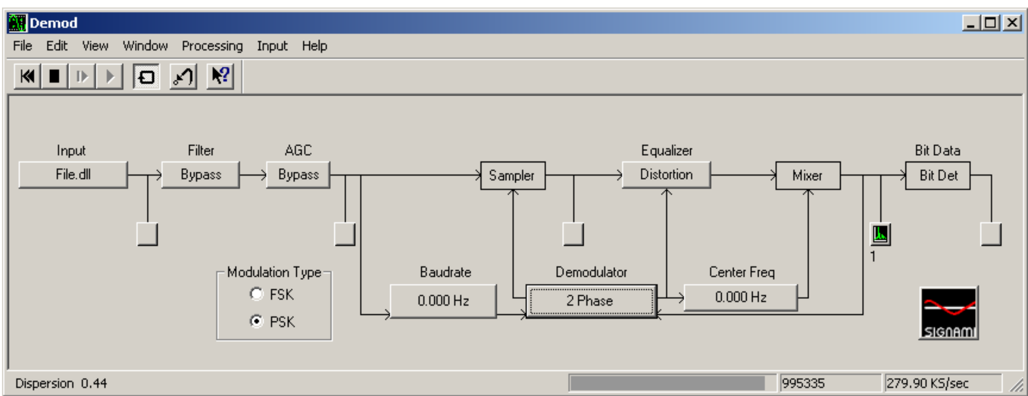


Figure 42. QPSK Demod test point at mixer output

The test point display should like the graphic below titled "Equalized." Notice there are four groupings but they are not grouped tightly.

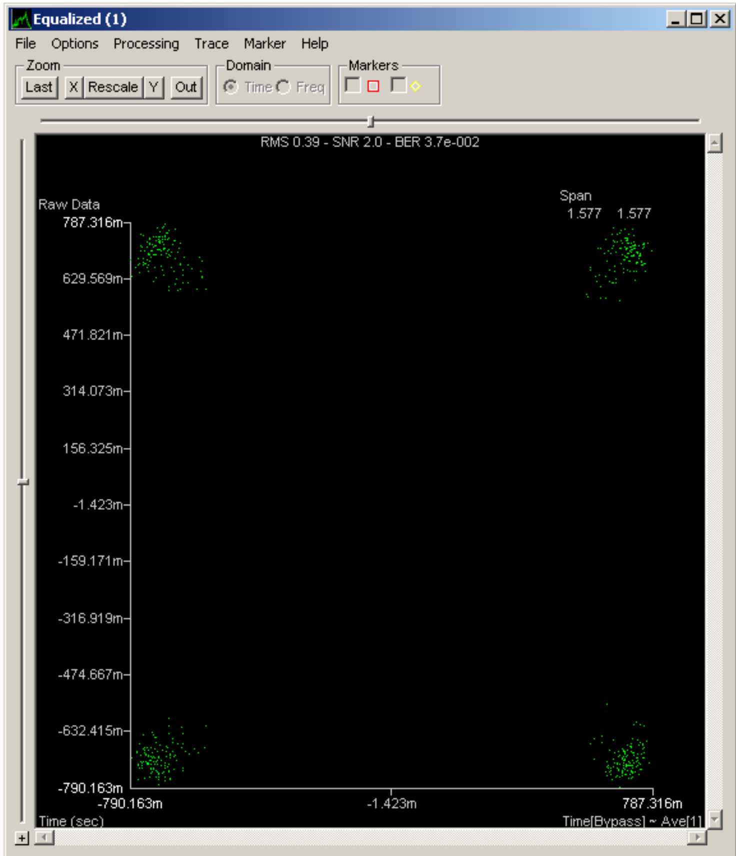


Figure 43. QPSK Demod test point display with poor grouping

Select the button labeled “2 Phase” under Demodulator. The following window appears. The tight groupings on this embedded display are the ideal 2-phase signal presentation.

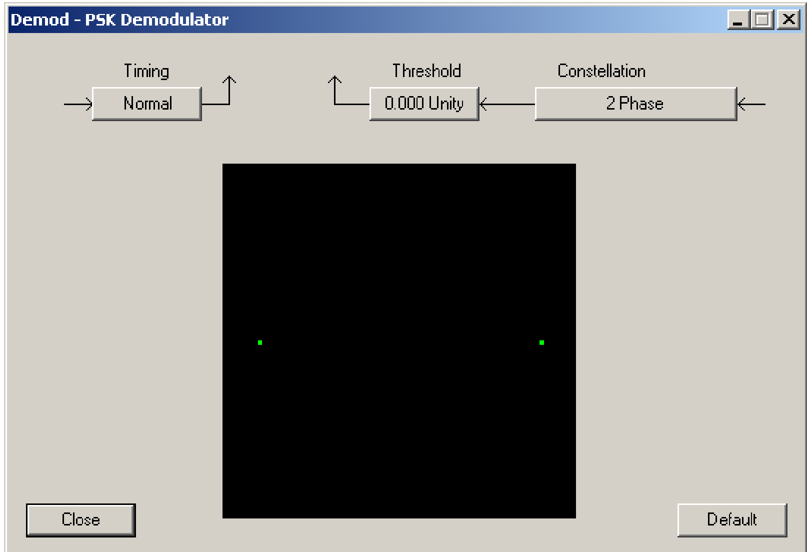


Figure 44. QPSK PSK demodulator

With the “Demod-PSK Demodulator” window and the “Equalized” windows both visible, select the “2 Phase” button under Constellation on the “Demod-PSK Demodulator” window and choose a different constellation until a tight grouping is presented in the “Equalized” display. Since there are four groupings, try the various constellations with “4” in the title. The “4 Phase” setting will present a grouping like the one below, which is the best grouping available.

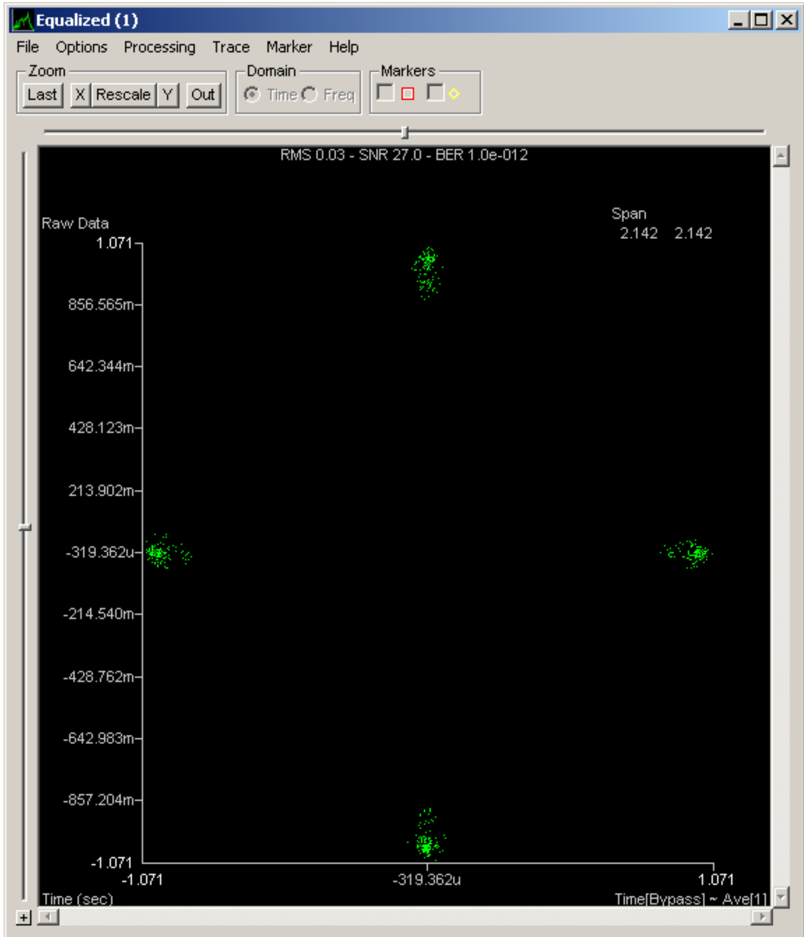


Figure 45. QPSK Demod test point display with optimal grouping

This is the desired presentation, thus confirming this is a Quadrature Phase-Shift Keyed signal.

E. QPSK ANALYSIS RESULTS

Signalworks® was used to generate and analyze a Quadrature Phase-shift Keyed signal. Processing the signal with Preview allowed the analyst to measure the center frequency and baud rate. These measured parameters were exported to the Demod allowing the user to test different modulation techniques until a desired grouping was achieved. The first display from the Demod showed large groupings of dots, which is an indication of the wrong modulation type used for demodulation or excessive noise in the transmission. By cycling through

various modulation types, a tighter grouping of dots was achieved when selecting 4 Phase modulation. Both displays had four points but the phase shift position on the polar plot was different.

IV. QUADRATURE AMPLITUDE MODULATION SIGNAL ANALYSIS

A. OVERVIEW OF QUADRATURE AMPLITUDE MODULATION SIGNALS

1. Signal Characteristics

The next logical step in increasing spectrum efficiency after the development of phase modulation was to combine it with amplitude modulation. This is termed multilevel modulation or Quadrature Amplitude Modulation (QAM). In a QAM constellation, the points, also known as phasors, are increased to provide more data throughput at the same bandwidth. By varying the amplitude, multiple points can be placed along a given phase vector. The figure below shows only one point per phase vector but the amplitude varies for each point to maintain separation and minimize interference. In this example, there are eight waveforms or 8-ary, with four vectors at one amplitude and the other four vectors at a different amplitude. Each vector is separated by 45°.

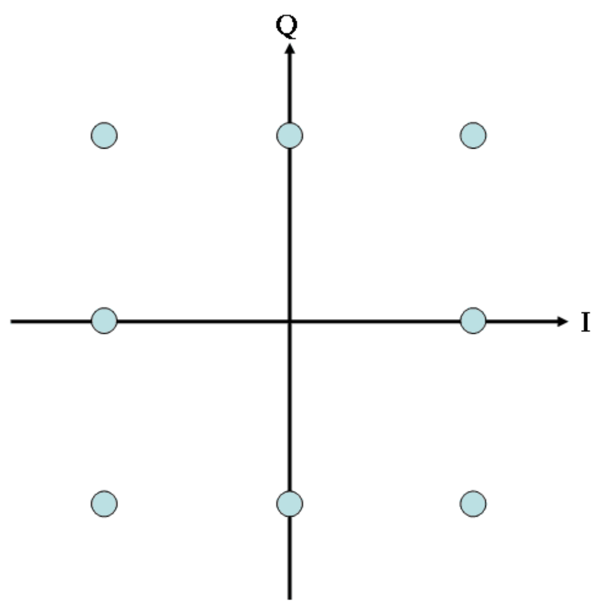


Figure 46. 8 level QAM polar plot

The mathematical equation for a QAM signal combines the equation for Amplitude-Shift Keyed and Phase-Shift Keyed signals. The resulting formula

$$s_i(t) = \sqrt{\frac{2E_i}{T}}\cos[\omega_0 t + \phi_i] \quad \begin{array}{l} 0 \le t \le T \\ i = 1, \ldots, M \end{array}$$

shows an indexing component for both the amplitude and the phase. The parameter E_i represents the energy of a symbol on the polar plot, T is the symbol time, and ϕ_i is the phase of a symbol.

2. Applications

The first mention of combining phase and amplitude modulation in a communications system was in 1960 by C.R. Cahn (Hanzo, Webb and Keller 739). He described a multilevel modulated system to include more than one transmitted amplitude at a given phase. His conclusions stated multilevel modulated systems, those with amplitude and phase modulation, increased the throughput when 16 or more states were used. While PSK modulation got its start in space communications, QAM had difficulty overcoming distortion from nonlinear amplifiers used on low-power satellites. QAM did have success in modem applications and, when linear amplification was introduced in 1982, the road in space implementation was paved.

B. GENERATING QAM TEST SIGNAL WITH SIGNALGEN

1. Procedural Guidance

This portion of the thesis begins the systematic procedures defining how to use the signal generation capabilities of Signalworks® with QAM signals. To create and save signals within Signalworks®, the SignalGen application will be used. The following steps detail how to create a QAM signal.

2. Creating a QAM Signal using the Signalworks® SignalGen Application

To open SignalGen with default parameter settings, hold SHIFT while double clicking the SignalGen icon if installed on the desktop or select "All Programs>Signalworks>SignalGen." The first window that appears allows users to recall normal parameter settings, user defined settings, or default settings. Select "Cancel" to use default settings.

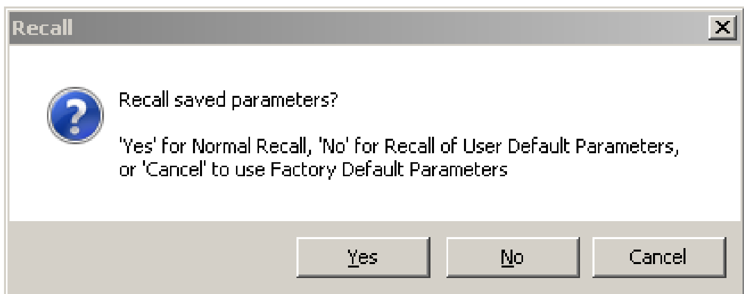


Figure 47. Recall default parameters window

Close the "Tip of the Day." The SignalGen window is now displayed. Click on the "Bit Operations" button. A new window pops up showing various tool palette input operations. Drag and drop the "QPSK Perm" and "LRS Encode" tools into the right-hand side of the window in the "Applied Operations" space. Click "OK."

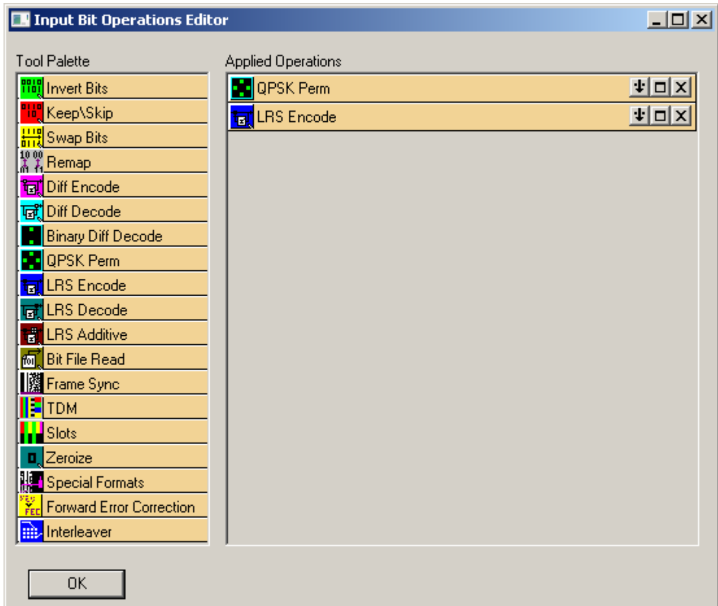


Figure 48. Input Bit Operations Editor

Click on the "Signal" button underneath the baseband operations label in the SignalGen window.

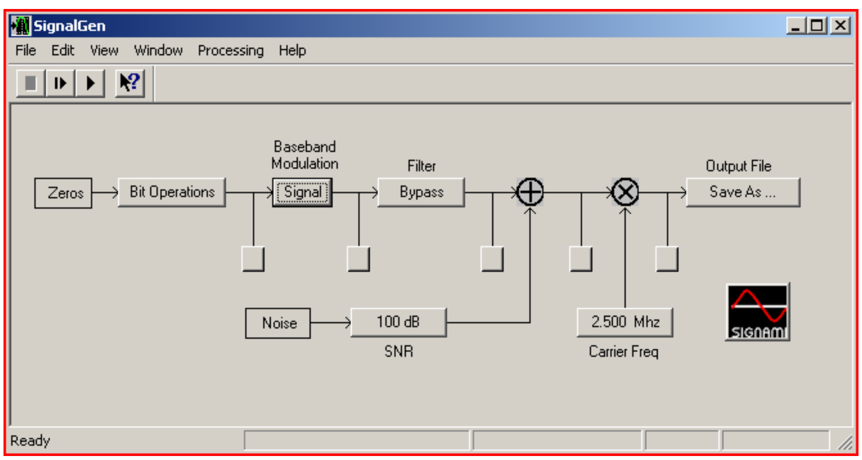


Figure 49. SignalGen for QAM procedures

The SignalGen Modulation window pops up. Select "PSK" on the left hand side of the window. Select the "2 Phase" button next to the Constellation label and select "8 State QAM." The Bit Rate will automatically change to 3.750Mbps. Leave all settings in their default configuration. Click "Close."

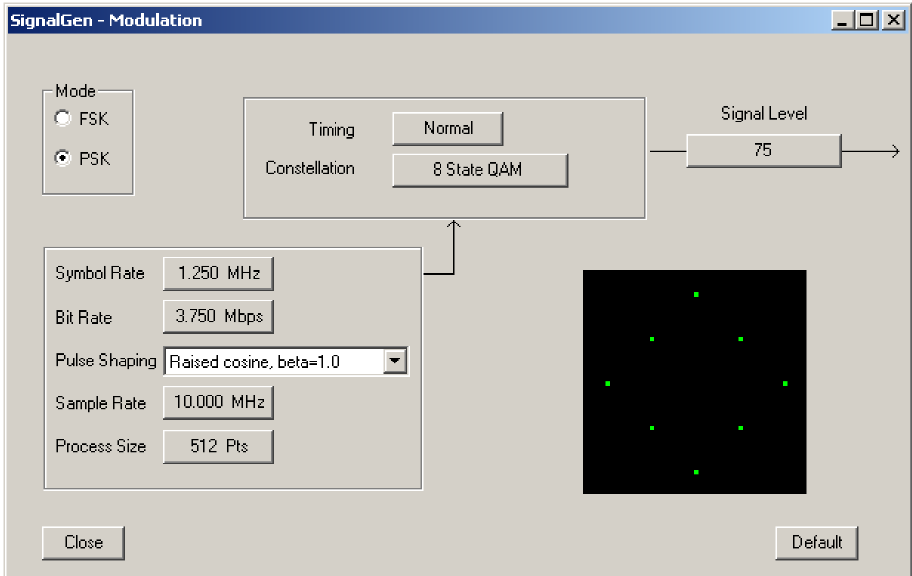


Figure 50. SignalGen Modulation window for QAM

We will now change the carrier frequency to 2.750MHz. In the SignalGen window, select the "Carrier Frequency" button on the lower left. Move the mouse over the arrow buttons directly under the column display and change the entry from 2.500 to 2.750. Click "Close."

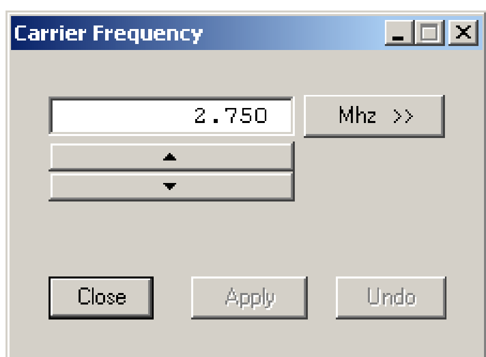


Figure 51. Carrier frequency set to 2750 KHz

Now the signal is ready to be viewed on a display prior to saving it for further analysis. The unlabeled boxes in the SignalGen window are for opening display plots. Select the test point display that comes after the Baseband Modulation box.

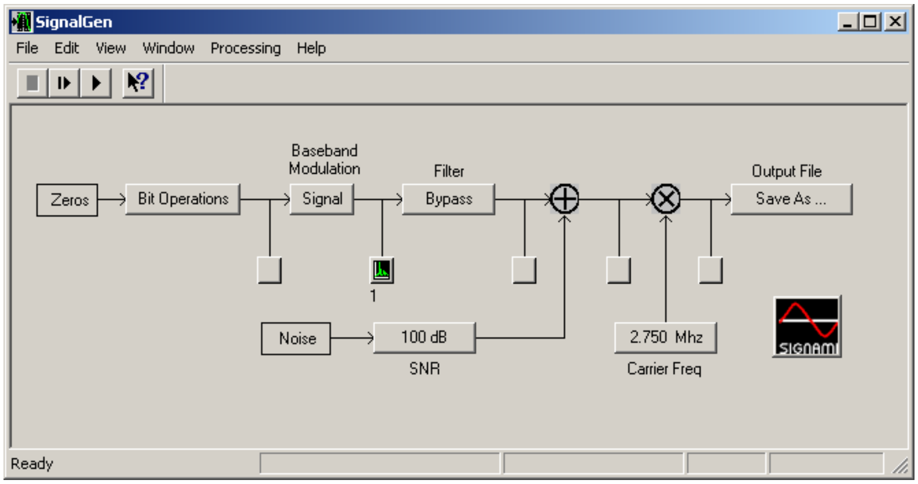
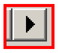


Figure 52. SignalGen test point of Baseband Modulation output

This will open up a blank Baseband Modulated display similar to an oscilloscope. With both the SignalGen and the Baseband Modulated windows within view, select the “play” button  at the top left of the SignalGen window. The display should now show a QAM signal like the one below.

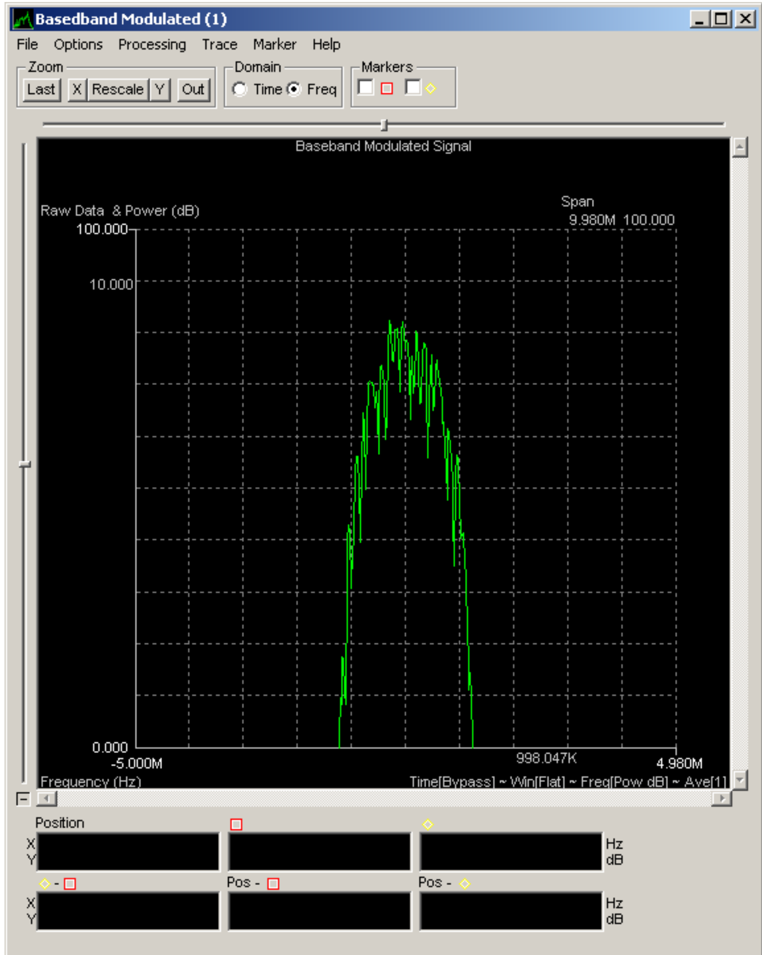


Figure 53. QAM Baseband Modulation test point display

Let the signal continue to play and select the "Save as…" button underneath the Output File label on the SignalGen window. Select the desired directory where you would like to store this custom file and ensure the extension is "byt." Name the file and select "Save." When the save is complete, you can stop playing the QAM signal you just created. The next step is to open Preview and begin doing the analysis on this signal. Close the SignalGen window.

C. INITIAL QAM ANALYSIS WITH PREVIEW

1. Procedural Guidance

A QAM test signal has just been created using SignalGen. The signal is ready to be analyzed using the Preview application within Signalworks®. The

Preview application allows us to measure some basic parameters and prepare the signal for further analysis using the Demod application.

2. Initial QAM Analysis using the Signalworks® Preview Application

Open the Preview application in the same manner as you did with SignalGen. Hold the shift key and double click the Preview icon if installed on the desktop or select "All Programs>Signalworks>SignalGen." Again, select "Cancel" to resort to the default settings. Close the "Tip of the Day."

First, the QAM file saved in SignalGen must be loaded into the Preview application. Select the box labeled "File.dll" under Input.

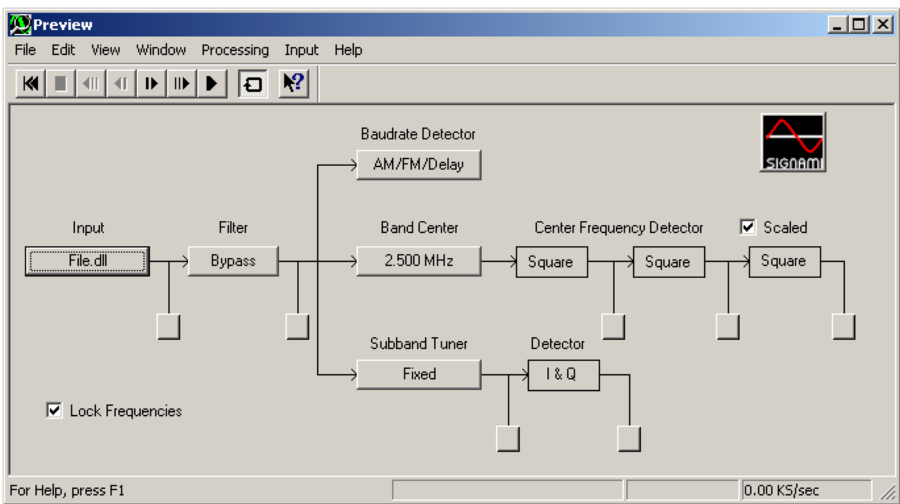


Figure 54. QAM Preview window

Select the "Select file" button on the left side of the window labeled File Parameters. Navigate to the directory where the QAM file was saved and select it. The window below shows the QAM file "8qam.byt" selected. Click "Close" on this window.

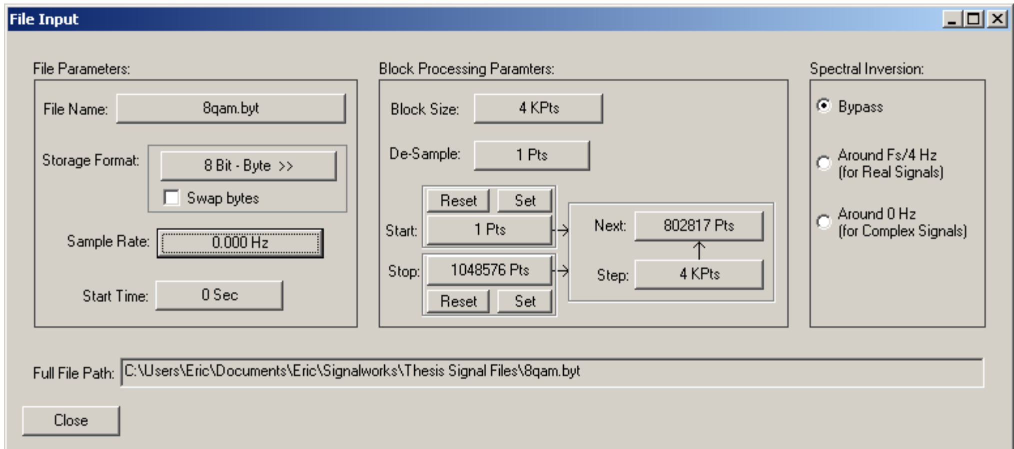
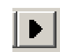


Figure 55. QAM file input selection

The QAM signal created earlier is now queued and ready to play and analyze with the Preview application. Select either the normal play  or the slow motion play  button at the top of the Preview window. Select the display button after the Input to view the QAM signal.

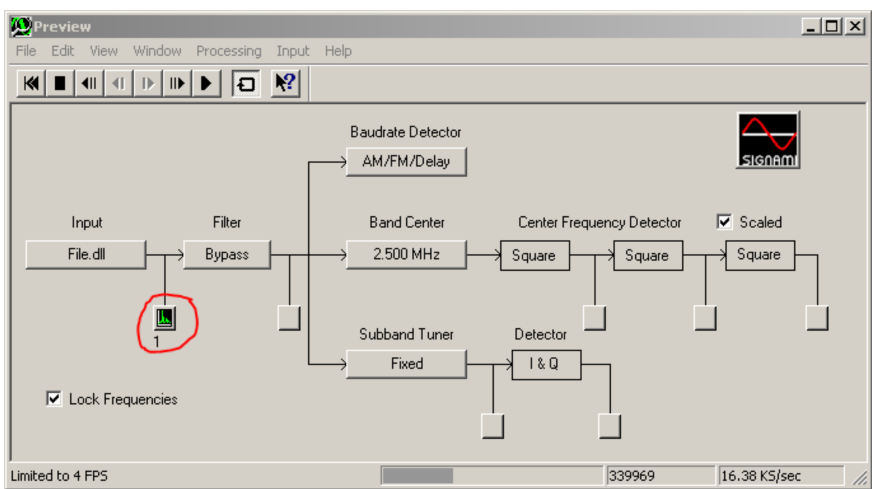


Figure 56. QAM Preview test point at file input

The signal should be displayed in the “Input” window and will look like the one below.

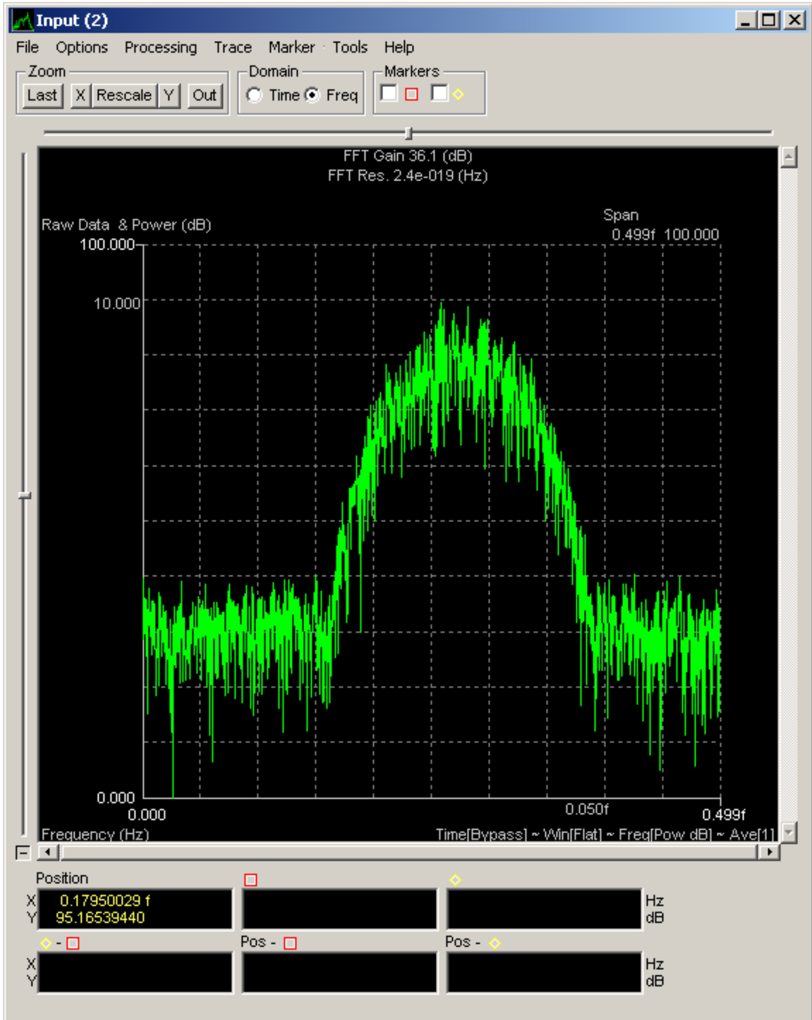


Figure 57. QAM Preview test point display

The first step in measuring the center frequency of this QAM is to set the approximate band center. In the Input display, which shows the QAM in frequency (x-axis) and amplitude (y-axis), pull down the Tools menu from the top and select "Set band center." Then move the cursor so that it is in the approximate middle of the QAM signal. Click on the display to set the band center. The result will be a zero value input to the band center entry.

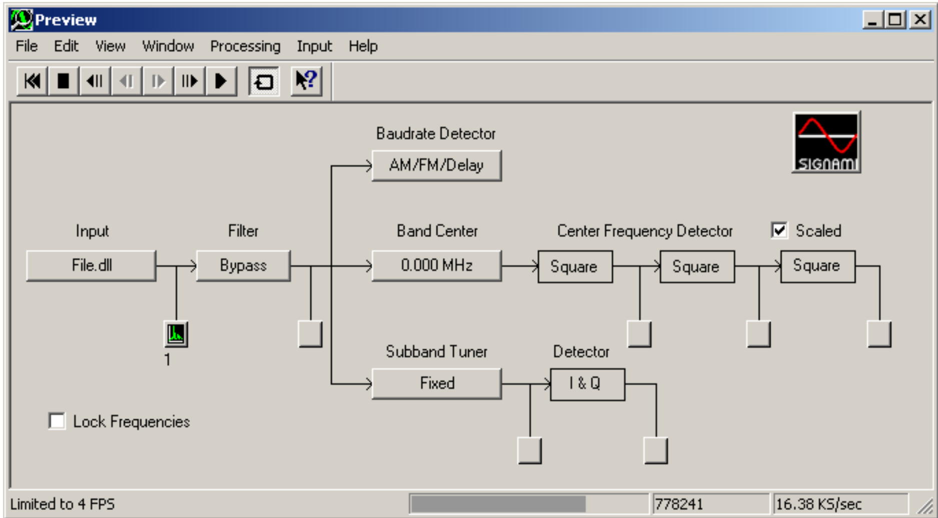


Figure 58. QAM Preview band center specification

Open a test point display in the Center Frequency Detector portion of the Preview window after the first "Square" box. Notice that the display that opens does not reveal a center frequency spike. This is an indication that the signal of interest may not be a simple PSK. Close this display and open a test point display after the second Square block. By double squaring the frequency in a QAM, the center frequency will be revealed.

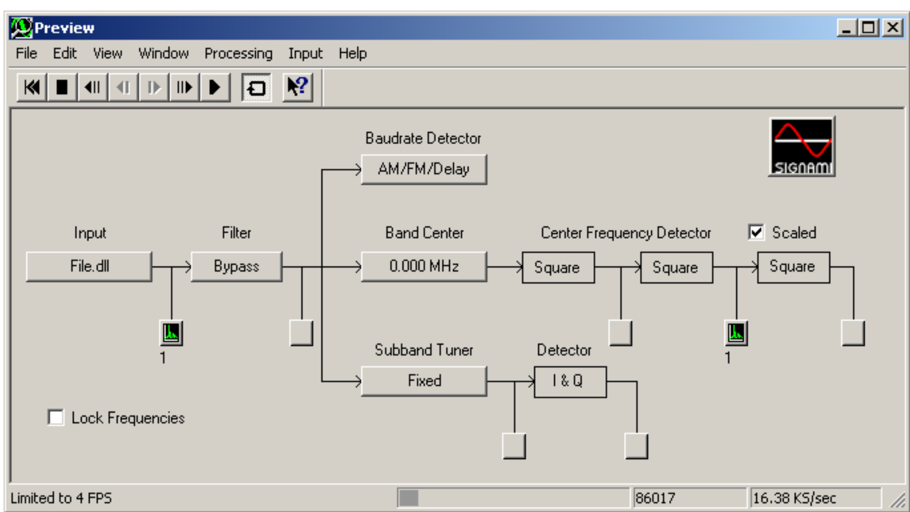


Figure 59. QAM Preview test point at Center Frequency Detector

The display that opens is titled “CF^4(2)” which indicates you are looking at the center frequency double squared. The display will show the QAM signal with a prominent spike in the center of the signal. Select the square marker at the top of the window. The marker should appear at the top of this spike and the frequency is reflected in the bottom of the window.

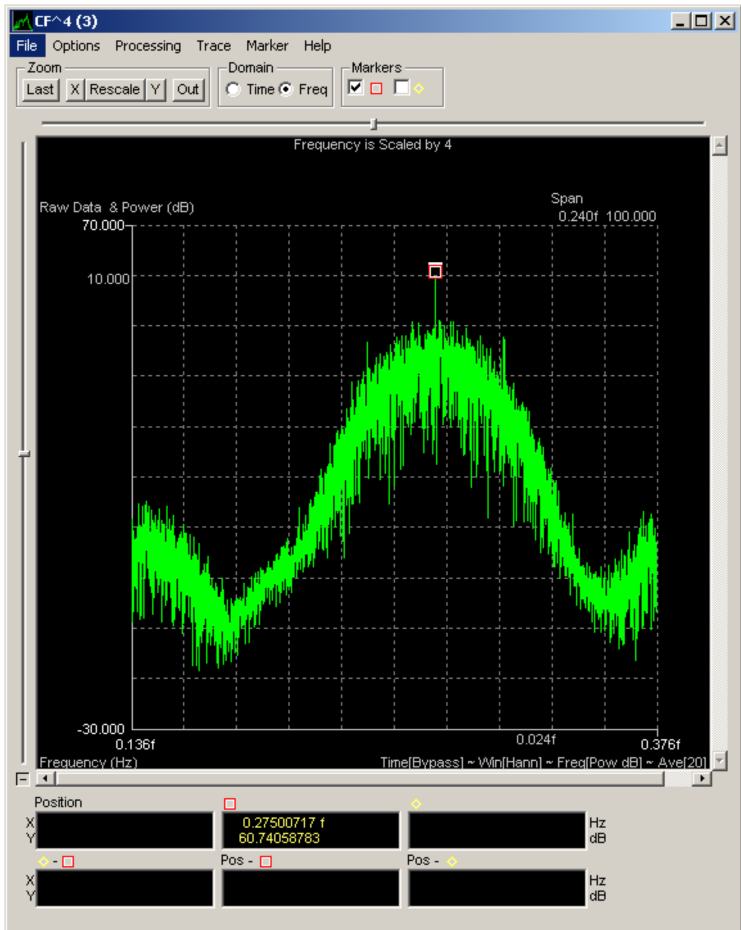


Figure 60. QAM center frequency marker

The center frequency should be 2.750 MHz, which corresponds to what was defined as the carrier frequency in SignalGen when creating this signal. Leave this window open.

Next, we will derive the symbol (baud) rate. Assure the QAM signal sample is playing, in either full motion or slow motion, and then select the “AM/FM/Delay” button underneath the Baudrate label on the Preview window. A

new window will open, select the AM Detector test point to bring up a new display. Select the other marker at the top of the window and assure the marker is placed on the left most spike within the AM Baudrate display.

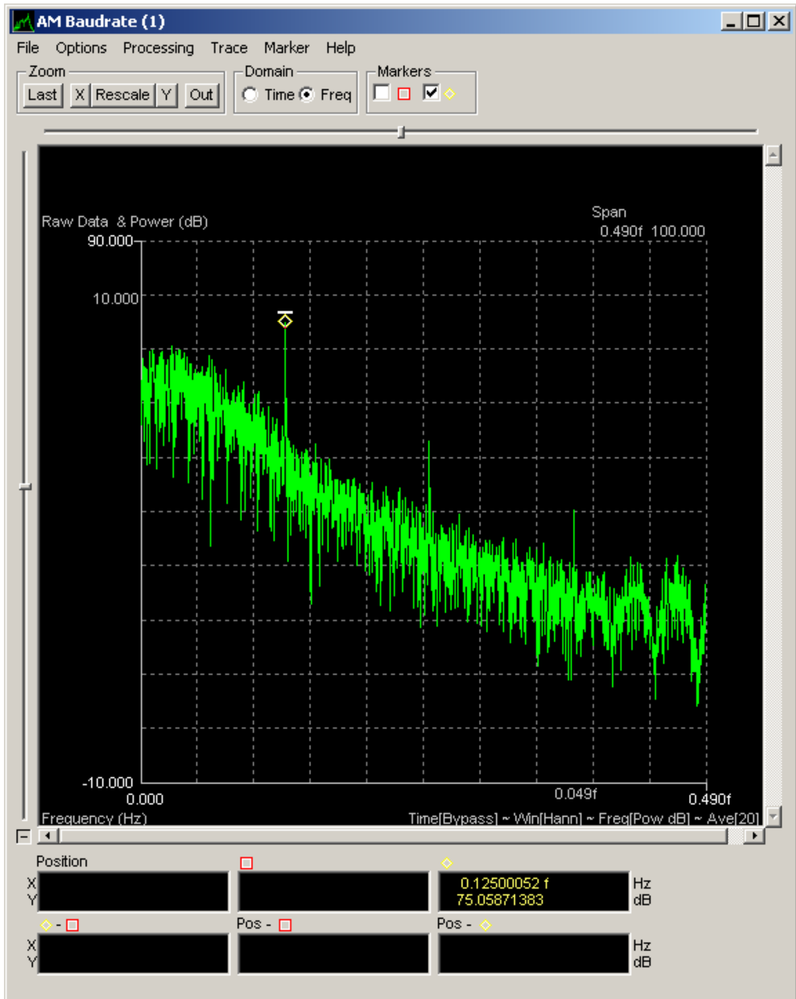


Figure 61. QAM baud rate display

You can drag the marker to the left most spike if it is not placed there automatically. The measurement at the bottom of the display should read "1250," which is the symbol rate specified when building this signal file in SignalGen. The fact that the carrier frequency was revealed only when double squaring the center frequency means this is a quadrature signal instead of a single carrier signal. Bit rate, measured in bits per second, is twice the symbol rate for a QAM signal because there are now twice as many positions, or phase-

amplitude combinations, that can represent a symbol. Like the QPSK polar plot depicted in Figure 25, each position represents two bits; 00, 01, 10, and 11. A binary plot allows only a 1 or 0 at each position. Symbol rate is measured in baud, or symbols per second. The measured symbol rate was 1.25 MBaud and when doubled results in a bit rate of 2.5 Mbit/s.

Ensure that the carrier frequency and symbol rate displays are active, with their respective markers indicating the measured parameters. Select the "File" pull-down menu and select "Export / Save for Demod." The window that appears shows all active display parameters.

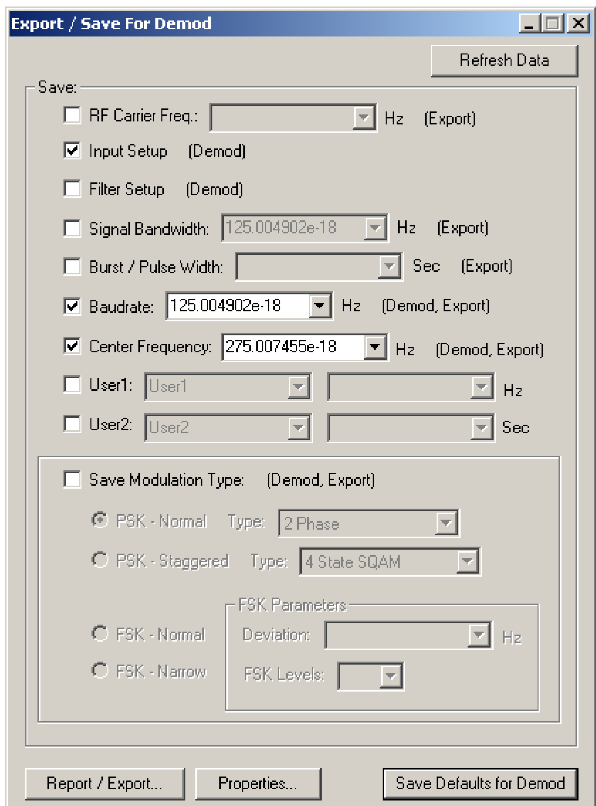


Figure 62. QAM export/save for Demod

Select "Save Defaults for Demod" at the bottom of the window. This saves your measured parameters for the Demod.

D. ADDITIONAL QAM ANALYSIS WITH DEMOD

1. Procedural Guidance

Demod is Signalworks'® advanced analysis application. It can demodulate signals and perform bit level analysis. Here, Demod will be used to define the modulation of the QAM signal created earlier using SignalGen, which was initially processed using Preview.

2. Advanced QAM Analysis with the Signalworks® Demod Application

Demod will be used to identify the type of signal that is being analyzed. Open Demod by double either clicking on the icon or selecting it from the Program menu. Do not hold shift. Demod will open with the parameters from Preview already loaded.

Open the test point after the mixer.

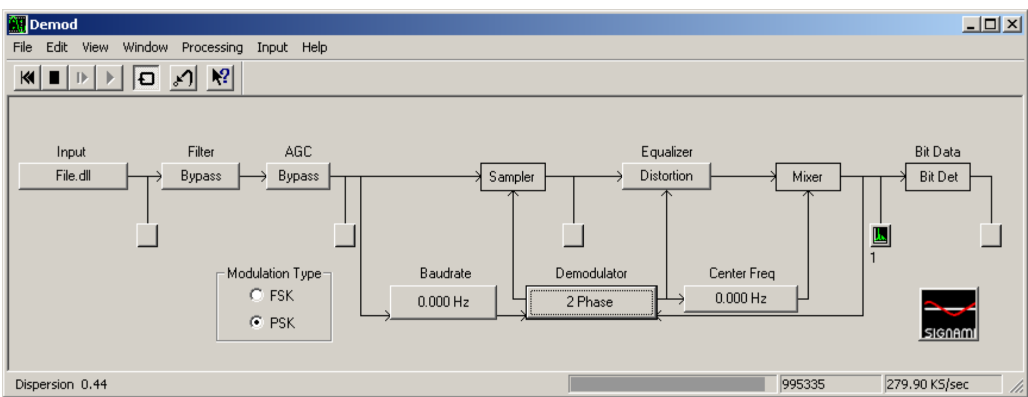


Figure 63. QAM Demod test point at mixer output

The test point display should like the graphic below titled "Equalized." Notice there are eight groupings, but they are not grouped tightly.

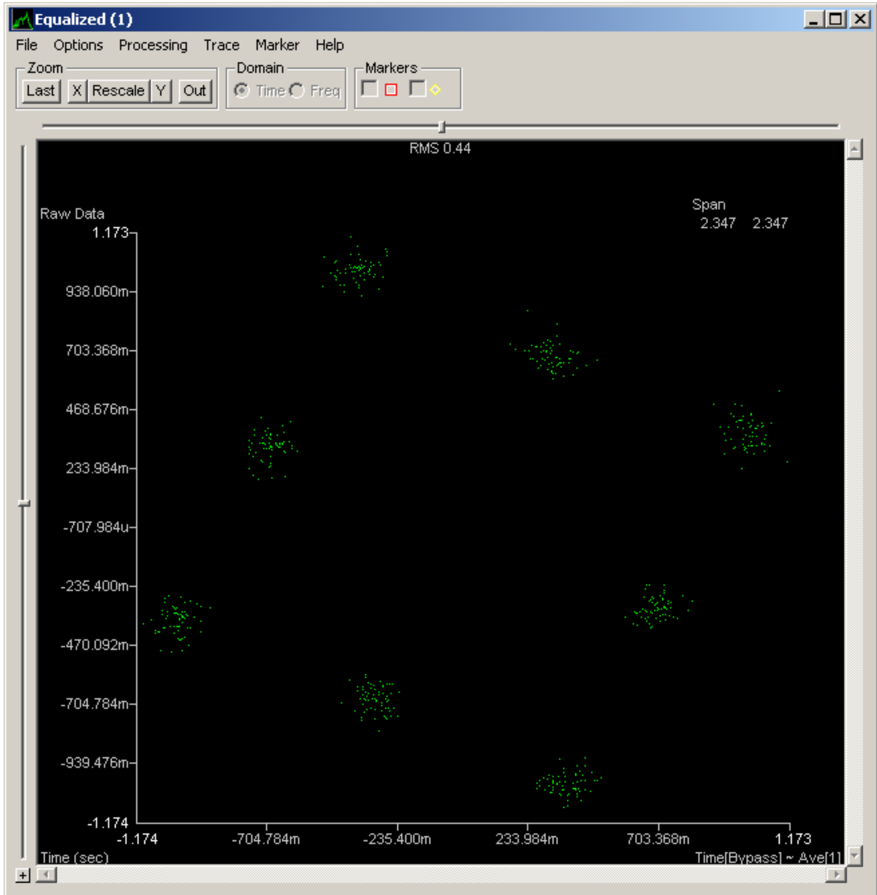


Figure 64. QAM Demod test point display with poor groupings

Select the button labeled “2 Phase” under Demodulator. The following window appears. The tight groupings on this embedded display are the ideal 2-phase signal presentation.

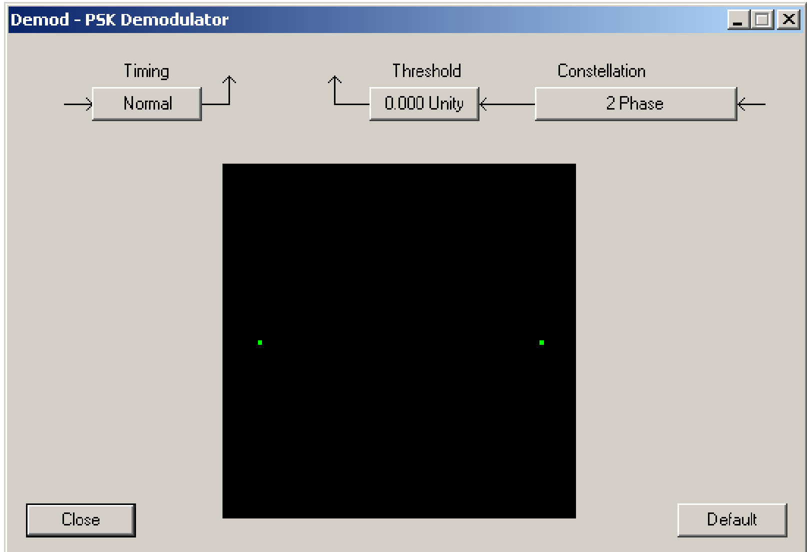


Figure 65. QAM Demod PSK Demodulator window

With the “Demod-PSK Demodulator” window and the “Equalized” windows both visible, select the “2 Phase” button under Constellation on the “Demod-PSK Demodulator” window and choose a different constellation until a tight grouping is presented in the “Equalized” display. Since there are eight groupings, try the various constellations with “8” in the title. The “8 State QAM” setting will present a grouping like the one shown below in Figure 66, which has been annotated to explain the varying amplitudes and phases of a QAM signal.

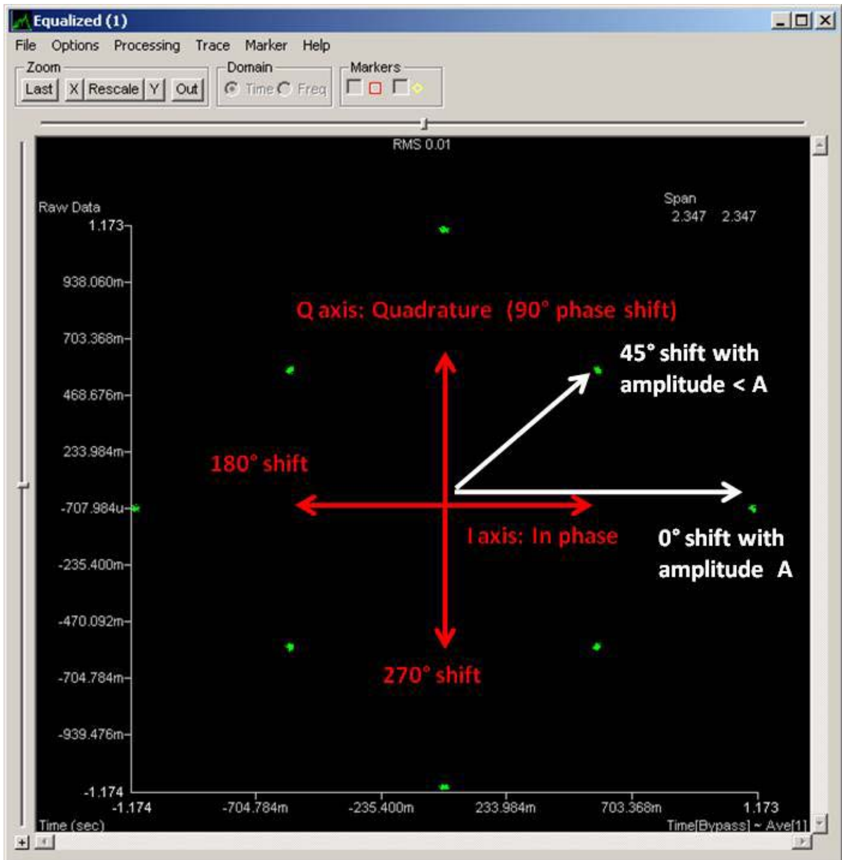


Figure 66. QAM Demod test point display with acceptable groupings

Similar to a QPSK signal, various phases are used in a QAM signal to represent symbols. Now the added parameter of amplitude is incorporated to increase the number of possible symbols. This variation in amplitude is shown with the white arrows. The grouping with a 0° shift is higher in amplitude than the grouping at the 45° shift. The variation in amplitude and phase allows for more symbol positions while maintaining separation from other positions to minimize interference. The display in Figure 66 is the desired presentation, thus this signal is in fact an eight State-Quadrature Amplitude Modulated signal. In a normal QAM signal, symbol rate is based on four data signals 90° out of phase. Since this is an 8 State signal, multiply the symbol rate by 3 (8=2^3) to determine the bit rate. In this case, 1.250 MHz x 3 = 3.750 Mbps bit rate.

E. WORKING WITH ADVANCED QAM SIGNALS

1. Beyond 8-State QAM

Up to this point, the analysis has been focused on an 8-State QAM signal. This section supplements the procedures already discussed to allow the user to generate and analyze a 16- and 64-State QAM. In order to achieve more points in the constellation, the system would have to implement more amplitude and phase shifts. This increases the data throughput at the cost of more induced error since the spacing between constellation points has decreased.

2. Generating 16-State QAM with Signalworks®

Following the same procedures used to create the 8-State QAM. When clicking the "Signal" button under the Baseband Modulation label on the SignalGen main window, the SignalGen Modulation window pops up. Select "PSK" on the left hand side of the window. Select the "2 Phase" button next to the Constellation label and then select "16 State QAM" instead of 8-State QAM as in the earlier procedure. The Bit Rate will automatically change to 3.750Mbps. Leave all settings in their default configuration. Click "Close."

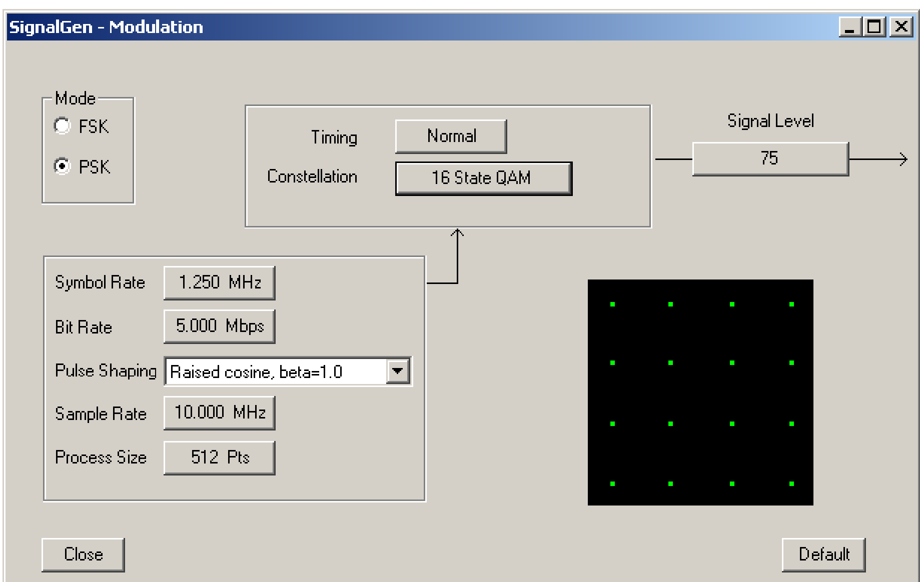


Figure 67. 16-State QAM SignalGen modulation window

We will now change the carrier frequency to 2.000MHz. In the SignalGen window, select the "Carrier Frequency" button on the lower left. Move the mouse over the arrow buttons directly under the column display and change the entry from 2.500 to 2.000. Click "Close."

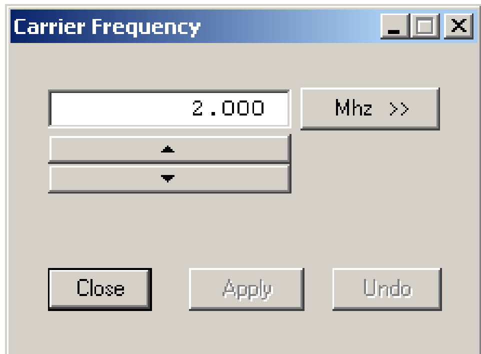


Figure 68.   16-State QAM Carrier frequency set to 2000 KHz

Follow the procedures provided in the 8-State directions to complete the generation of the 16-State QAM.

3. Generating 64-State QAM with Signalworks®

Following the same procedures used to create the 8-State QAM. When clicking the "Signal" button under the Baseband Modulation label on the SignalGen main window, the SignalGen Modulation window pops up. Select "PSK" on the left hand side of the window. Select the "2 Phase" button next to the Constellation label and select "64-State QAM." The Bit Rate will automatically change to 7.500Mbps. Leave all settings in their default configuration. Click "Close."

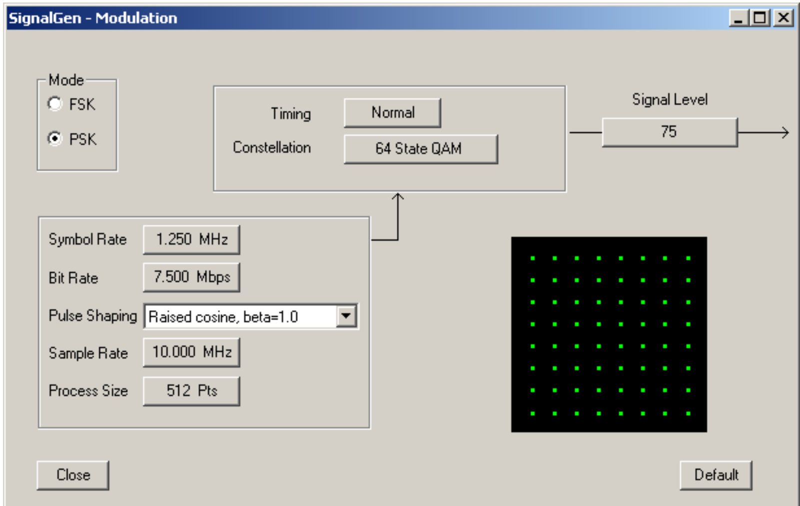


Figure 69. 64-State QAM SignalGen modulation window

We will now change the carrier frequency to 2.600MHz. In the SignalGen window, select the "Carrier Frequency" button on the lower left. Move the mouse over the arrow buttons directly under the column display and change the entry from 2.500 to 2.600. Click "Close."

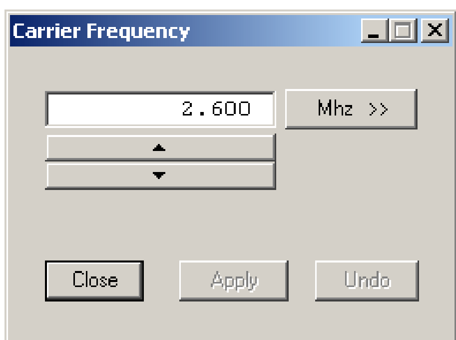


Figure 70. 64-State QAM Carrier frequency set to 2,600 KHz

Follow the procedures provided in the 8-State directions to complete the generation of the 64-State QAM.

4. Initial analysis of 16-State QAM with Preview

The procedure within Preview when analyzing 16-State QAM is the same as 8-State QAM up to the point where center frequency is measured. Open a test point display in the Center Frequency Detector portion of the Preview

window after the first “Square” box. Notice that the display the opens does not reveal a center frequency spike. This is an indication that the signal of interest may not be a more simple two phase PSK. Close this display and open a test point display after the second Square block. By double squaring the frequency in a QAM, the center frequency will be revealed.

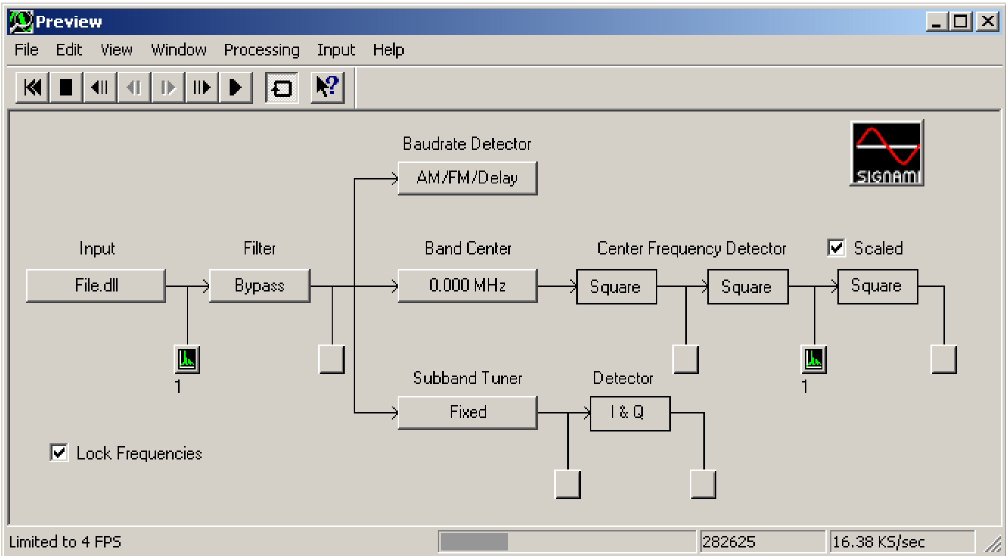


Figure 71.   16-State QAM Preview test point for double squared center frequency

The display that opens is titled “CF^4(2)” which indicates you are looking at the center frequency double squared. The display will show the QAM signal with a prominent spike in the center of the signal. Select the square marker at the top of the window. The marker should appear at the top of this spike and the frequency is reflected in the bottom of the window.

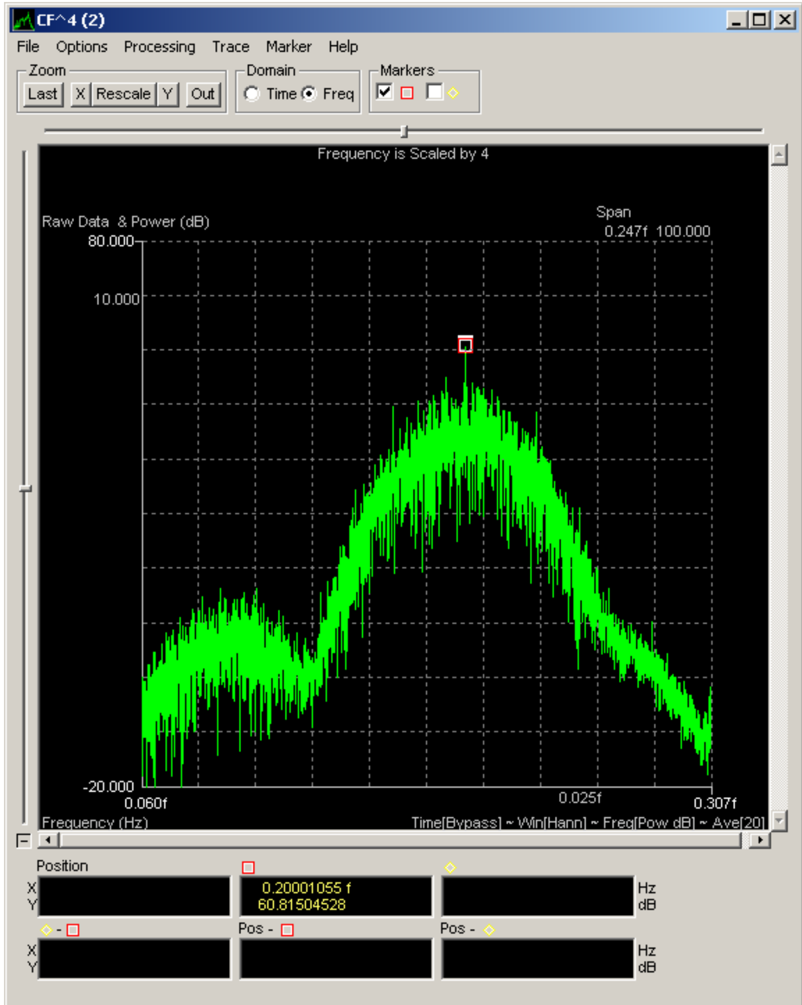


Figure 72. 16-State QAM test point display for double carrier frequency

The center frequency should be 2.000 MHz, which corresponds to what was defined as the carrier frequency in SignalGen when creating this signal. Leave this window open.

Next, we will derive the symbol (baud) rate. Assure the QAM signal sample is playing in full or slow motion, and then select the "AM/FM/Delay" button underneath the Baudrate label on the Preview window. A new window will open, select the AM Detector test point to bring up a new display. Select the other marker at the top of the window and assure the marker is placed on the left-most spike within the AM Baudrate display.

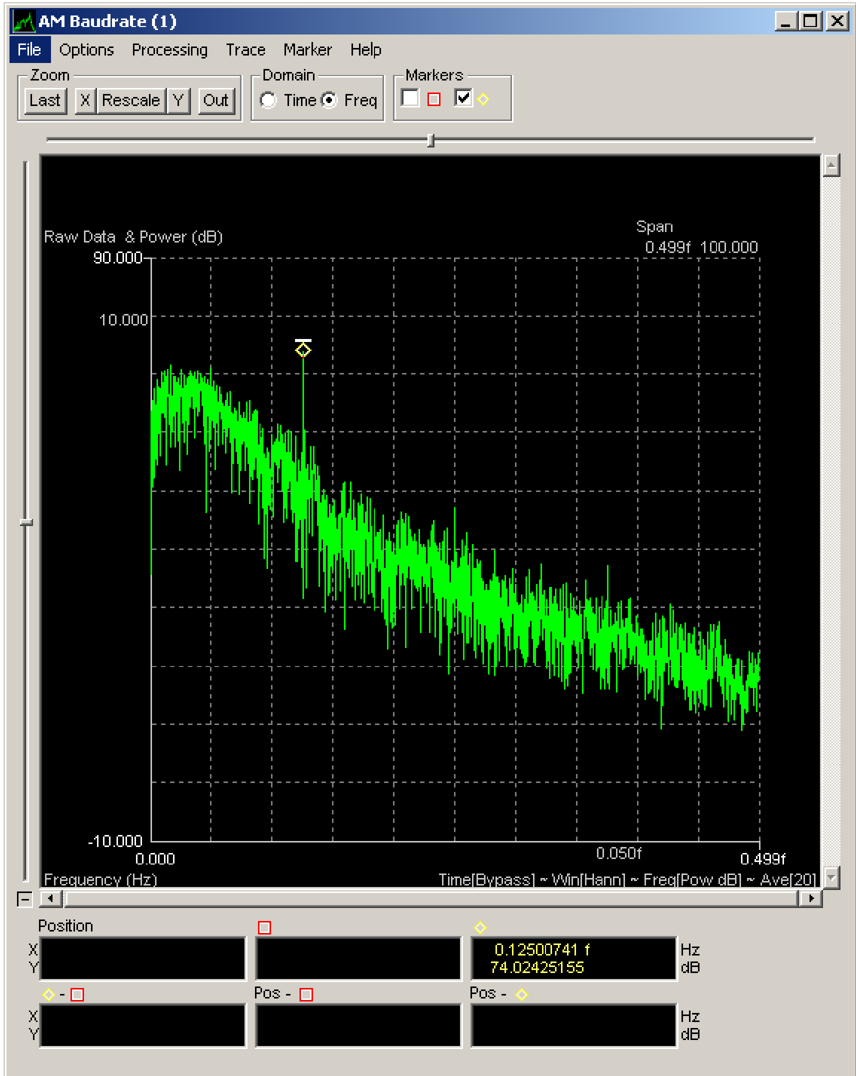


Figure 73. 16-State QAM baud rate display

You can drag the marker to the left most spike if it is not placed there automatically. The measurement at the bottom of the display should read "1250," which is the symbol rate specified when building this signal file in SignalGen. Now the type of signal must be defined, since the bit rate will be a multiple of the symbol rate.

Ensure that the carrier frequency and symbol rate displays are active with their respective markers indicating the measured parameters. Select the "File" pull-down menu and select "Export / Save for Demod." The window that appears shows all active display parameters.

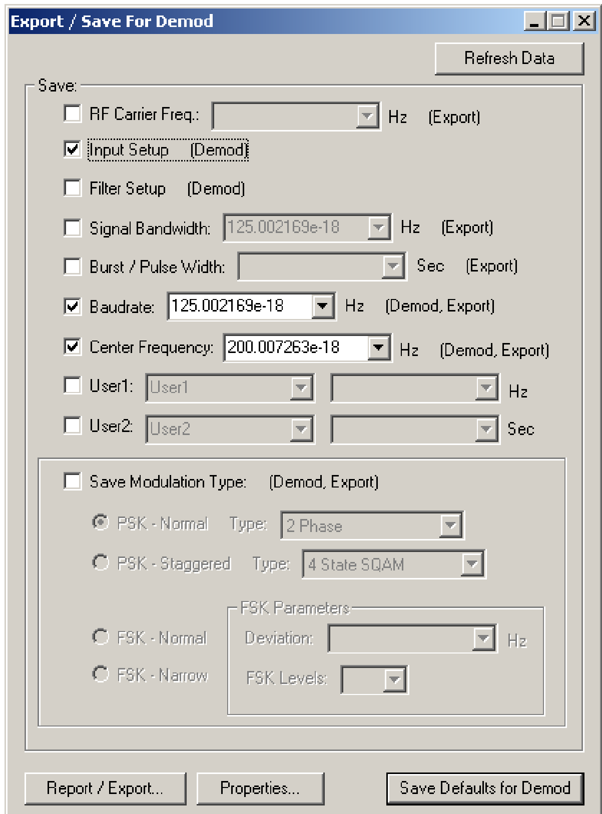


Figure 74. 16-State QAM export/save for Demod window

Select "Save Defaults for Demod" at the bottom of the window. This saves your measured parameters for the Demod. This completes the procedures for generating a 16-State QAM. The next step is to start analysis in Preview.

5. Initial Analysis of 64-State QAM with Preview

The procedure within Preview when analyzing 64-State QAM is the same as 8-State QAM up to the point where center frequency is measured. Open a test point display in the Center Frequency Detector portion of the Preview

window after the first “Square” box. Notice that the display that opens does not reveal a center frequency spike. This is an indication that the signal of interest may not be a more simple two phase PSK. Close this display and open a test point display after the second Square block. By double squaring the frequency in a QAM, the center frequency will be revealed.

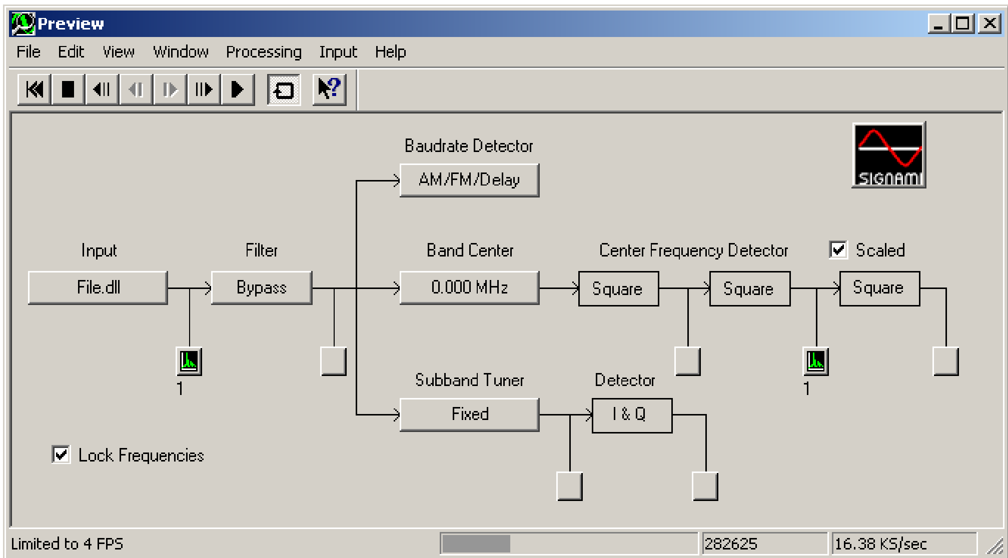


Figure 75.   16-State QAM test point for double frequency squaring

The display that opens is titled “CF^4(2),” which indicates you are looking at the center frequency double squared. The display will show the QAM signal with a prominent spike in the center of the signal. Select the square marker at the top of the window. The marker should appear at the top of this spike and the frequency is reflected in the bottom of the window.

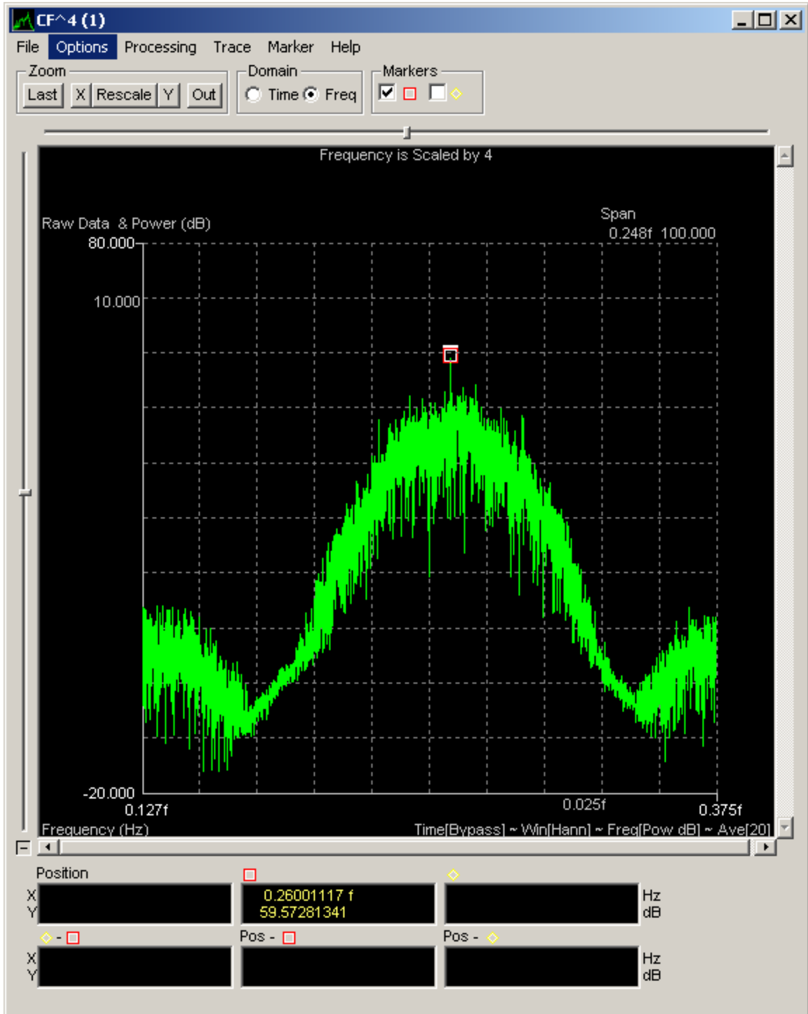


Figure 76. 16-State QAM center frequency display

The center frequency should be 2.600 MHz, which corresponds to what was defined as the carrier frequency in SignalGen when creating this signal. Leave this window open.

Next, we will derive the symbol (baud) rate. Assure the QAM signal sample is playing, in either full motion or slow motion, and then select the "AM/FM/Delay" button underneath the Baudrate label on the Preview window. A new window will open, select the AM Detector test point to bring up a new display. Select the other marker at the top of the window and assure the marker is placed on the left most spike within the AM Baudrate display.

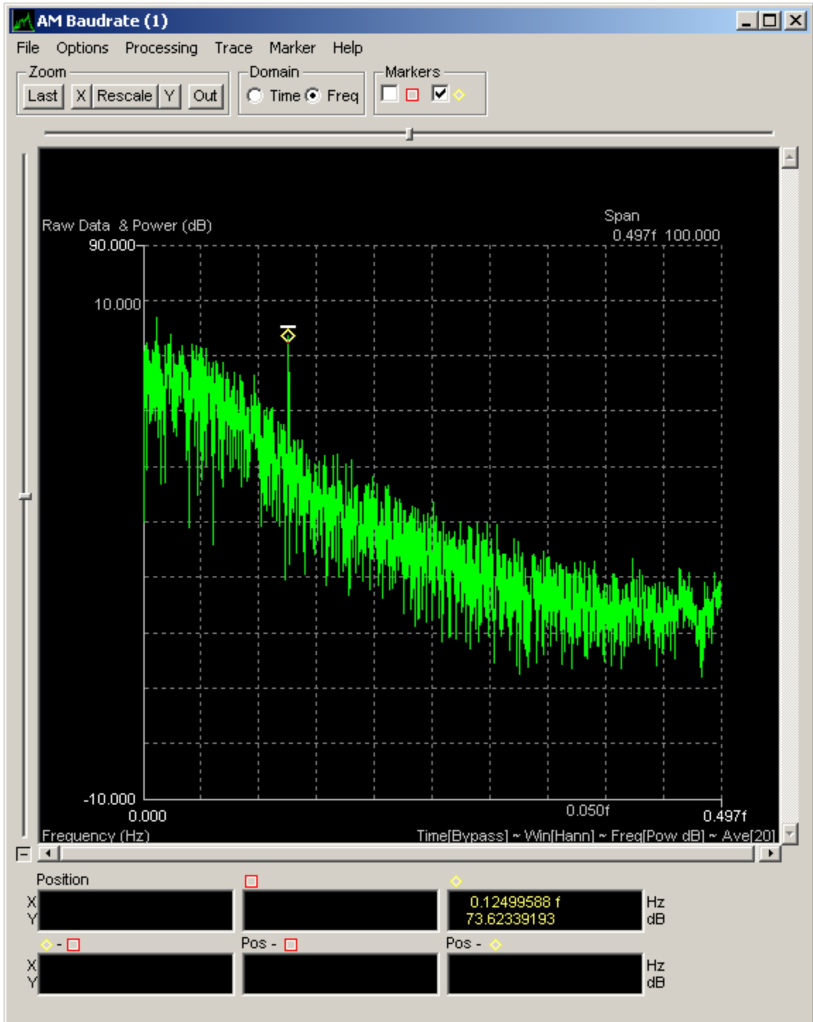


Figure 77. 16-State QAM baud rate display

You can drag the marker to the left most spike if it is not placed there automatically. The measurement at the bottom of the display should read ”1250,” which is the symbol rate specified when building this signal file in SignalGen. Now the type of signal must be defined since the bit rate will be a multiple of the symbol rate.

Ensure that the carrier frequency and symbol rate displays are active with their respective markers indicating the measured parameters. Select the “File” pull-down menu and select “Export / Save for Demod.” The window that appears shows all active display parameters.

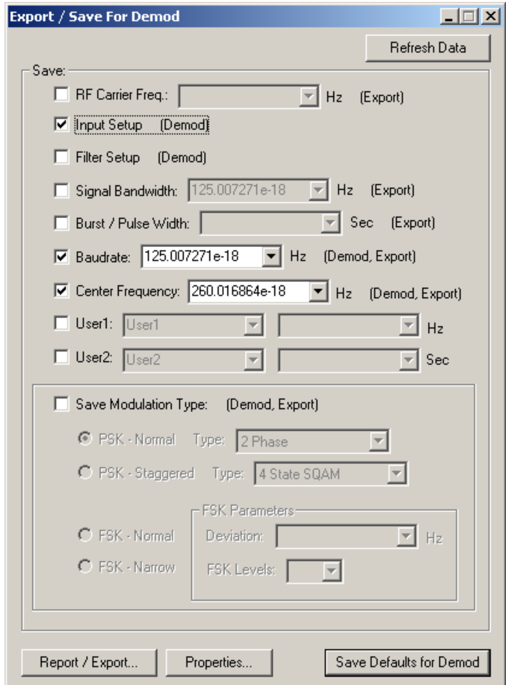


Figure 78. 16-State QAM export/save for Demod

Select "Save Defaults for Demod" at the bottom of the window. This saves your measured parameters for the Demod.

6. Advanced Analysis of 16-State QAM with Demod

Working with advanced QAM signals in Demod is similar to working with the 8-State signal. Open Demod, but do not hold the shift key down, and the settings saved in Preview will appear. Open the test point between the Mixer and Bit data.

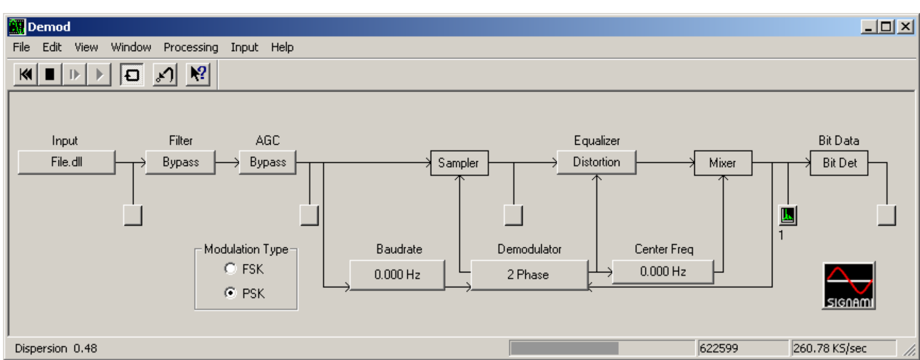


Figure 79. 16 State QAM Demod with mixer test point selected

The test point display should look like the graphic below titled “Equalized.” The pattern is hard to discern and the display presentation not tightly grouped as expected. Some different modulation types will be tested to see if the presentation changes.

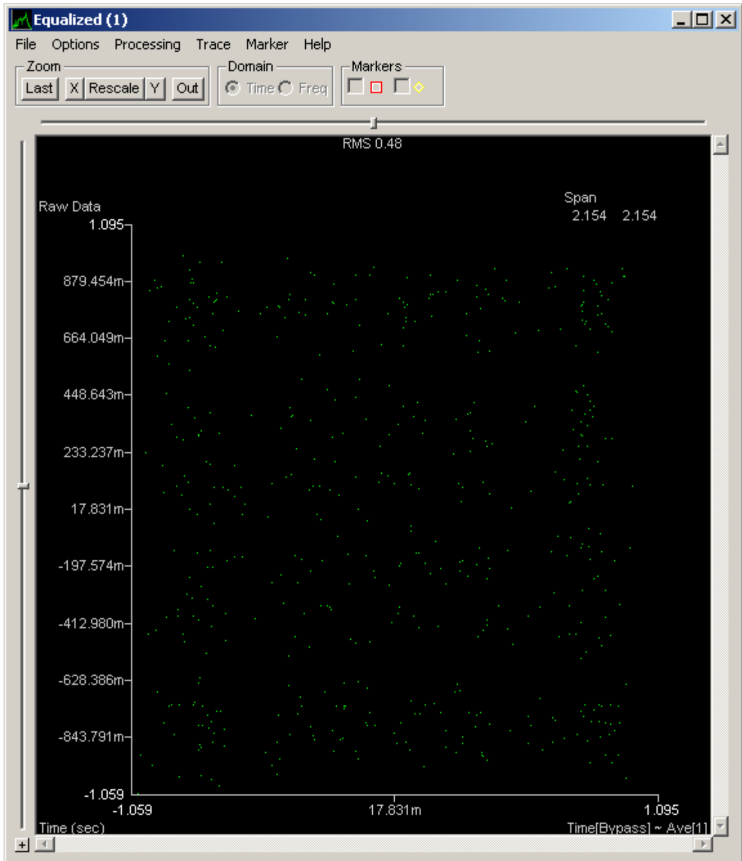


Figure 80. 16-State QAM mixer test point display with poor grouping

On the Demod window, select the button labeled “2 Phase” under Demodulator. The following window appears. The tight groupings on this embedded display are the ideal 2-phase signal presentation.

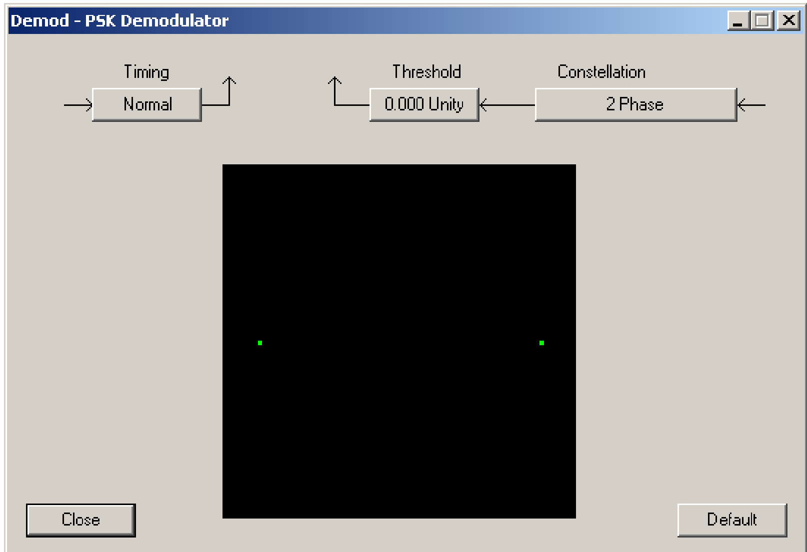


Figure 81. 16-State QAM Demod PSK Demodulator window

With the “Demod-PSK Demodulator” window and the “Equalized” windows both visible, select the “2 Phase” button under Constellation on the “Demod-PSK Demodulator” window and choose a different constellation until a tight grouping is presented in the “Equalized” display. Try the various constellations until a tightly grouped presentation is displayed. The “16-State QAM” setting will present a grouping like the one below.

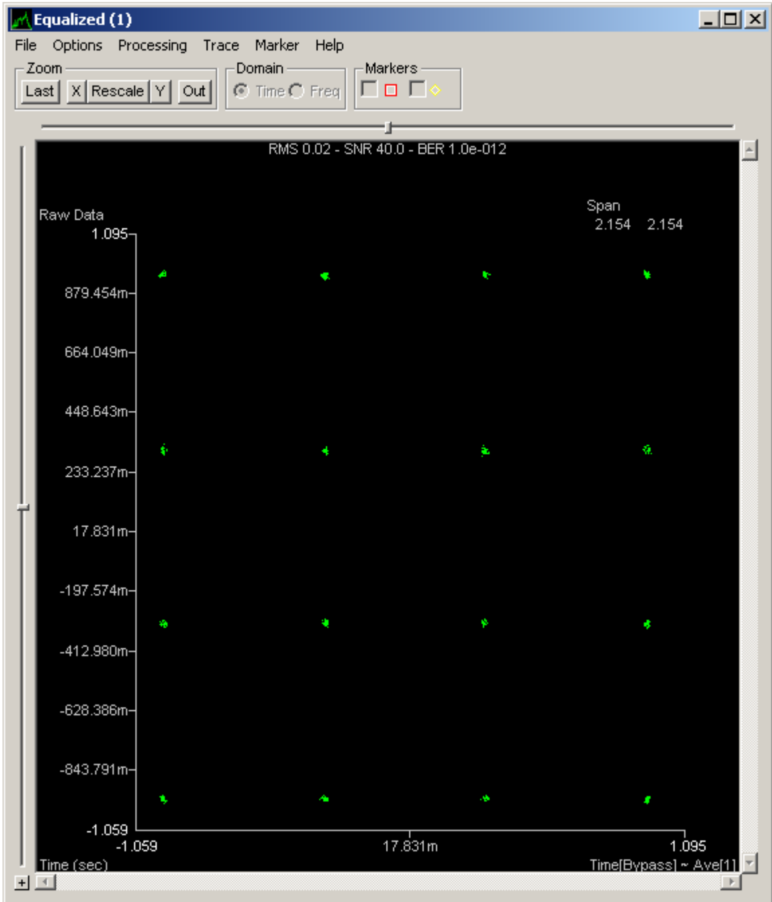


Figure 82. 16-State QAM mixer test point display with acceptable grouping

This is the desired presentation, thus this signal is confirmed as a 16-State Quadrature Amplitude Modulated signal. In a normal QAM signal, symbol rate is based on four data signals 90° out of phase. Since this is a 16-State signal, multiply the symbol rate by 4 (16=2^4) to determine the bit rate. In this case, 1.250 MHz x 4 = 5 Mbps bit rate.

7. Advanced Analysis of 64-State QAM with Demod

Working with advanced QAM signals in Demod is similar to working with the 8-State signal. Open Demod, but do not hold the shift key down, and the settings saved in Preview will appear. Open the test point between the Mixer and Bit data.

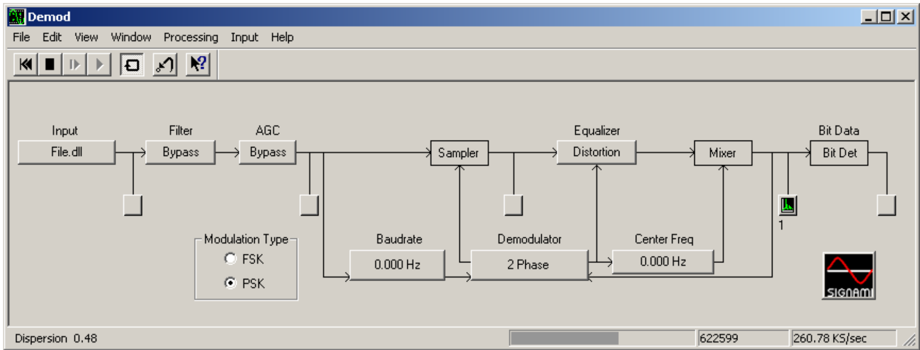


Figure 83. 64-State QAM Demod with mixer test point selected

The test point display should look like the graphic below titled “Equalized.” The pattern is hard to discern and the display presentation is not tightly grouped as expected. Some different modulation types will be tested to see if the presentation changes.

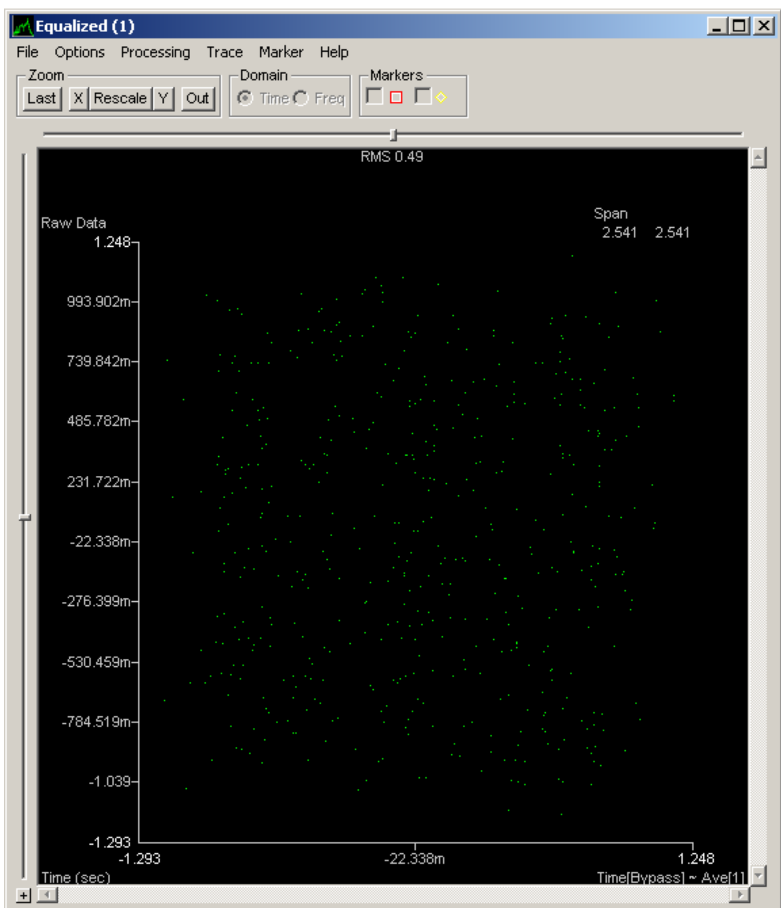


Figure 84. 64-State QAM mixer test point display with poor grouping

Select the button labeled "2 Phase" under Demodulator. The following window appears. The tight groupings on this embedded display are the ideal 2-phase signal presentation.

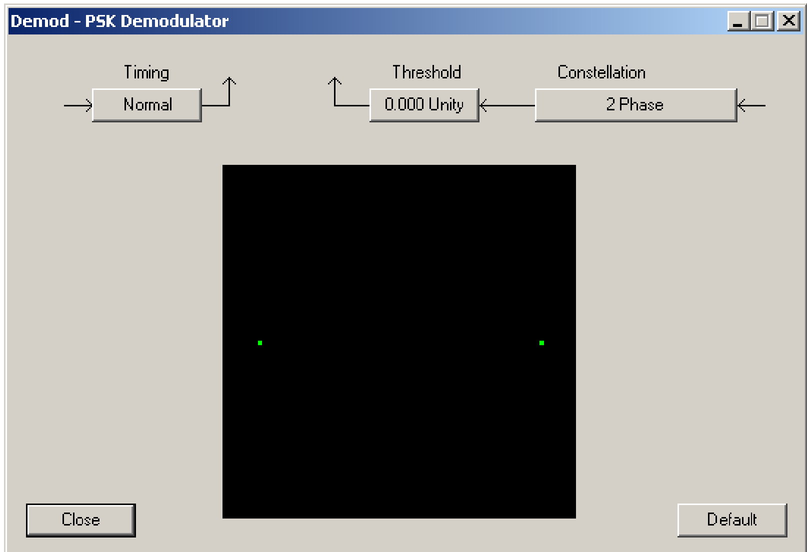


Figure 85. 64-State QAM Demod PSK Demodulator window

With the "Demod-PSK Demodulator" window and the "Equalized" windows both visible, select the "2 Phase" button under Constellation on the "Demod-PSK Demodulator" window and choose a different constellation until a tight grouping is presented in the "Equalized" display. Try the various constellations until a tightly grouped presentation is displayed. The "64-State QAM" setting will present a grouping like the one below.

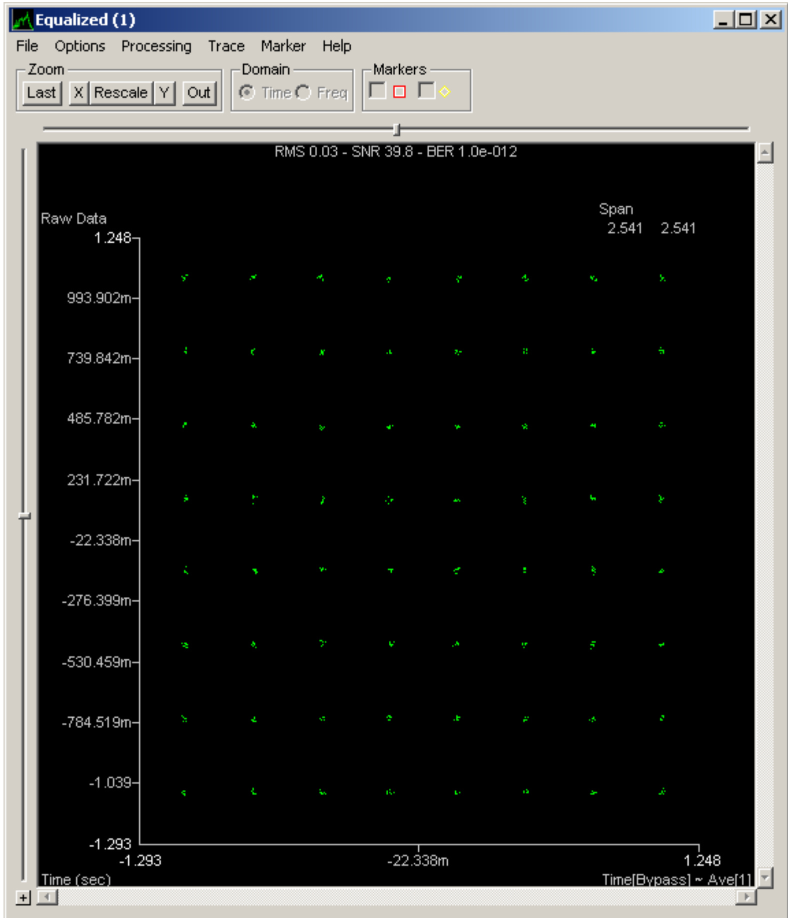


Figure 86. 64-State QAM mixer test point display with acceptable grouping

This is the desired presentation, thus this signal is confirmed as a 64-State Quadrature Amplitude Modulated signal. In a normal QAM signal, symbol rate is based on four data signals 90° out of phase. Since this is a 64-State signal, multiply the symbol rate by 6 (64=2^6) to determine the bit rate. In this case, 1.250 MHz x 6 = 7.5 Mbps bit rate.

F. QAM ANALYSIS RESULTS

Signalworks® was used to generate and analyze a Quadrature Amplitude Modulated signal. Processing the signal with Preview allowed the analyst to measure the center frequency and baud rate. These measured parameters were exported to the Demod, allowing the user to test different modulation techniques until a desired grouping was achieved. Initial views of the modulation display

showed poorly grouped dot patterns, indicating either incorrectly measured parameters or the wrong modulation selected by the demodulator. The carrier frequency and baud rate could be verified as the signal was generated in-house, so varying the modulation was the solution. By cycling through various modulation types, a tighter grouping of dots was achieved.

In designing a QAM constellation, the proximity of points is related to the error rate experienced during transmission. Various constellations can be used as well as power levels to overcome this error rate depending on the application.

V. WI-FI SIGNAL ANALYSIS

A. OVERVIEW OF WIFI SIGNALS

1. Signal Characteristics

This section discusses analysis of a signal sample file included with the Signalworks® installation. There are two Wi-Fi signals included in the sample file. For this analysis, the file title “wifi1.wrd” will be used. This file replicates an 802.11b standard Wi-Fi signal. The 802.11b standard is an extension of the 802.11 standard that increases the data throughput up to 11 Mbps using a frequency of 2.4 GHz range (Comer 719). The 802.11b standard was ratified in 1999, and products using the new extended standard reached the market in 2000. This new standard implemented Direct Sequence Spread Spectrum to increase data rate and maintain acceptable bit error rates (Heegard et al. 64).

2. Application

Initially, 802.11b networks were an improvement over original wireless technology established by the 802.11 standard. Now, due to interference with other devices operating at 2.4 GHz such as Bluetooth appliances, cordless phones, and microwaves, the 802.11b standard is less prevalent. Most modern 802.11g routers and access points are, however, backwards compatible with 802.11b.

B. INITIAL ANALYSIS WITH PREVIEW

1. Procedural Guidance

Signalworks® is limited in its ability to generate an 802.11b standard signal within SignalGen. Signals must be generated via an alternative source such as Matlab®. For this procedure, the Wi-Fi signal used for analysis will come from the sample signal file that is part of the standard Signalworks® installation. The signal will be initially processed in Preview and then exported to Demod for bit analysis.

2. Initial Analysis using the Signalworks® Preview Application

Open Preview by double clicking the Preview icon or selecting it from the Program menu under the Signalworks® folder. Remember to hold the shift key down prior to clicking on Preview in order to bring up the default parameters selection window. Select Cancel on the Recall window.

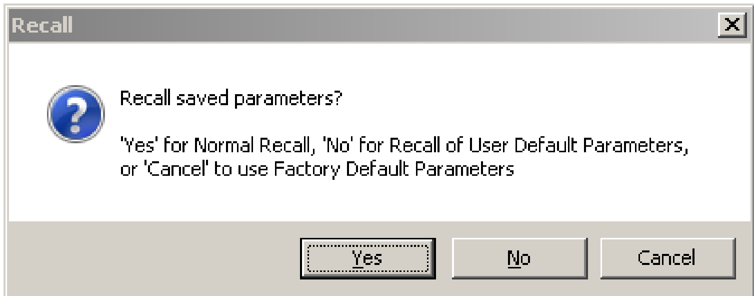


Figure 87. Recall window

Select Close on the "Tip of the Day" window. Click on the File.dll button to open the File Input window and click on the Select File button. Select the file named "wifi1.wrd." Do not close the File Input window. At this point, it is necessary to capture only a portion of this signal since the sample file has moments when the signal is active and moments when the signal is idle. For the purpose of analysis, only the active portion of the sample file is needed. Place the File Input window on one side of the screen and then open the test point just after the Input portion of the Preview window. In this next step, the Start and Stop features of Preview will be used. The buttons to control the Start and Stop function are located on the File Input window, which should still be open on your screen.

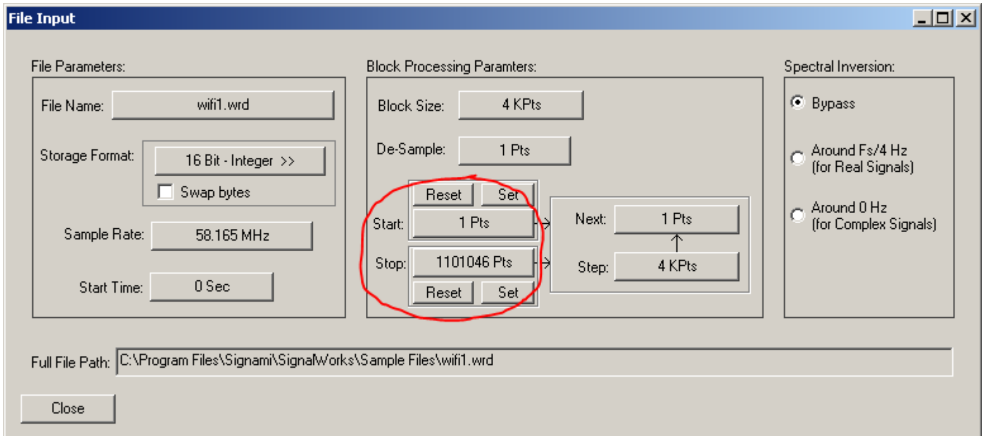


Figure 88. Start and Stop control buttons

It is recommended that you set up your screen as depicted in Figure 89.

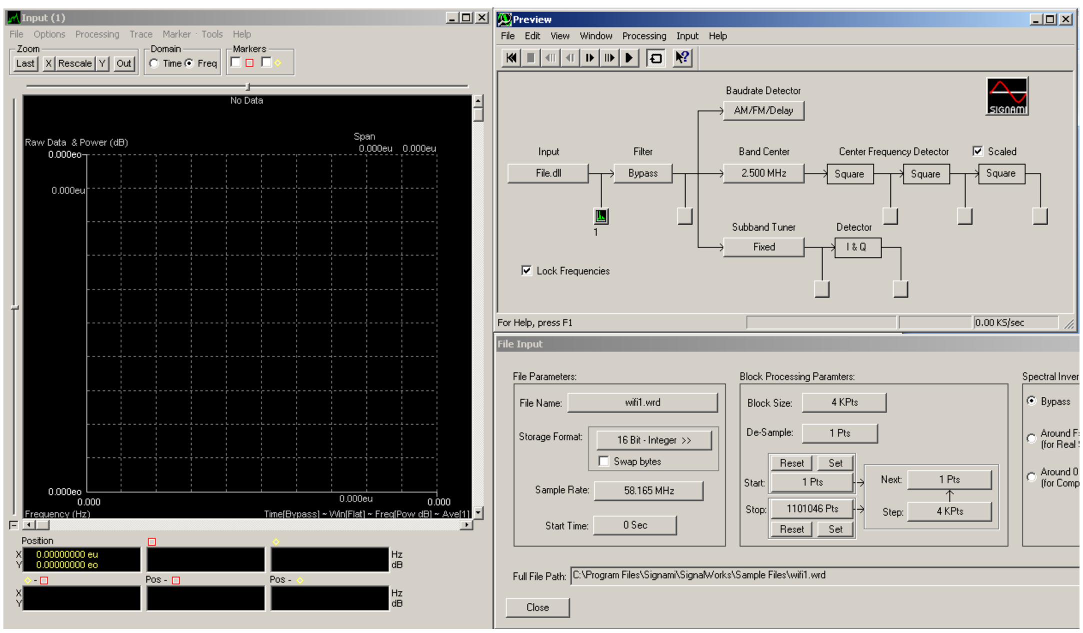


Figure 89. Test point display, Preview, and File Input window screen configuration

Select the "Slow Forward" button on the top left of the Preview window and observe the signal "wifi1.wrd" on the test point display. After establishing the pattern visually between the idle and active periods, stop the playback just after the signal transitions from idle to active. Then select the Set button for the Start parameter on the File Input window. Now the stopping point will be defined. Click on the "Slow Forward" button again and then stop playback just after the

signal transitions to idle. Use the “Step Back” button to go backward frame by frame until the first frame with the active signal is observed. Select the Set button for the Stop parameter on the File Input window. One active cycle of the signal has now been captured and will be used by Preview. If this procedure has been performed correctly, a constant active signal will be observed in the test point display when selecting the Play button. Once this is verified, close the File Input window.

The next step is to set up a filter to discard all but the peak power of the signal. With the Input test point display window active, select the Tools pull down menu and click on Filter Setup. Drag the cursor left to right across the peak of the signal. The resulting display will appear similar to Figure 90.

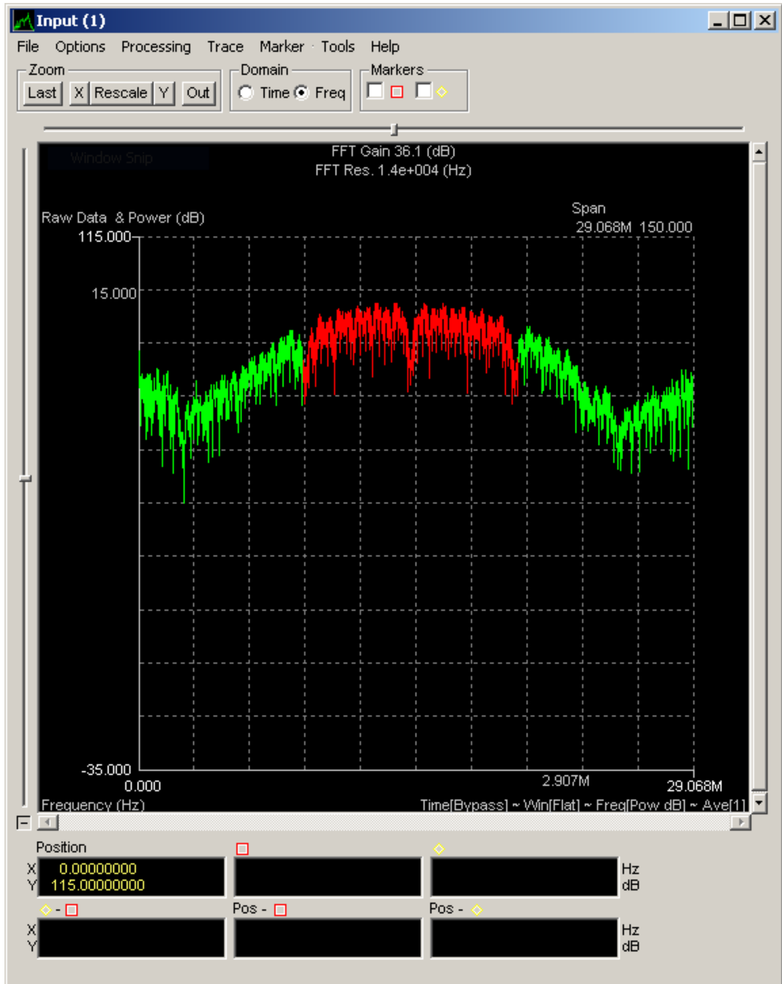


Figure 90. Filter Setup for wifi1.wrd

Close the Input test point display and select the first test point display in the Center Frequency Detector. Click on the red box marker at the top of the screen to measure the center frequency of this signal. Leave this display open.

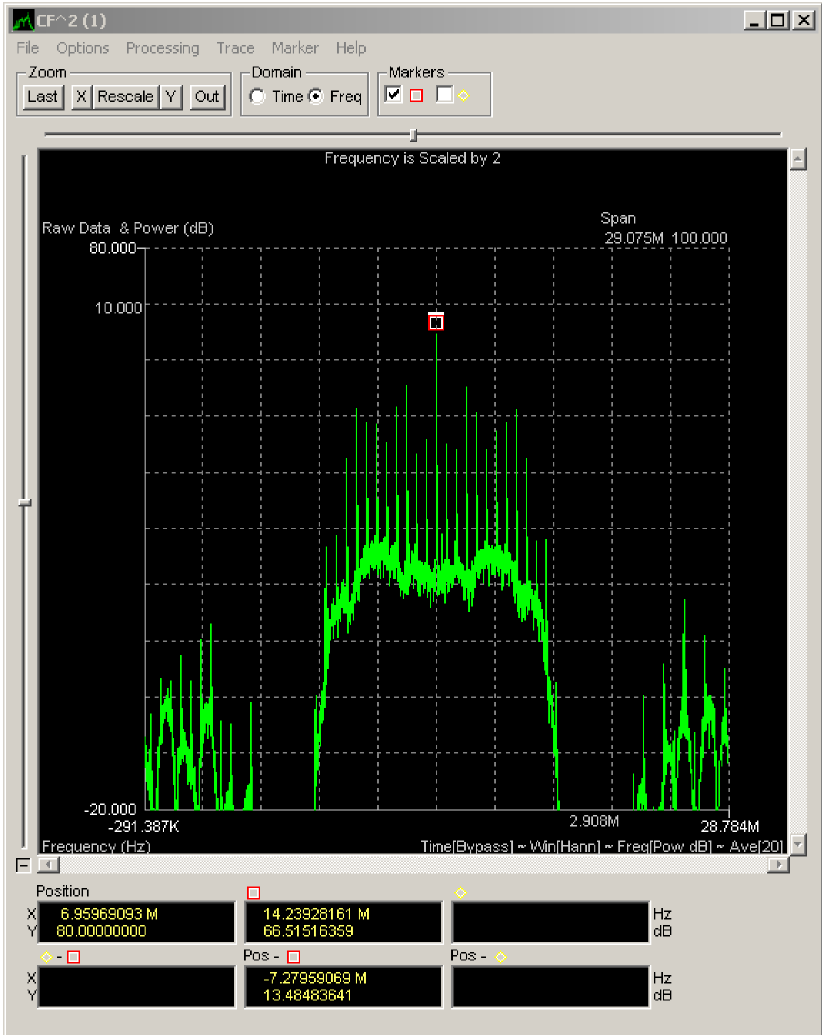


Figure 91. Center frequency measurement for wifi1.wrd

The measured center frequency should be approximately 14.239 MHz. Click on the AM/FM/Delay button to open the baud rate detector window. Select the test point for AM detector. This display will vary somewhat since the Start and Stop selections may differ from one user to the next. Here, it is useful to have some background knowledge of the signal being examined. In this case, an 802.11b signal has a standard baud rate of 11Mb/s. Knowing this, it is easier to see the break in pulse pattern just before a spike which when measured using the yellow diamond marker, can be correlated.

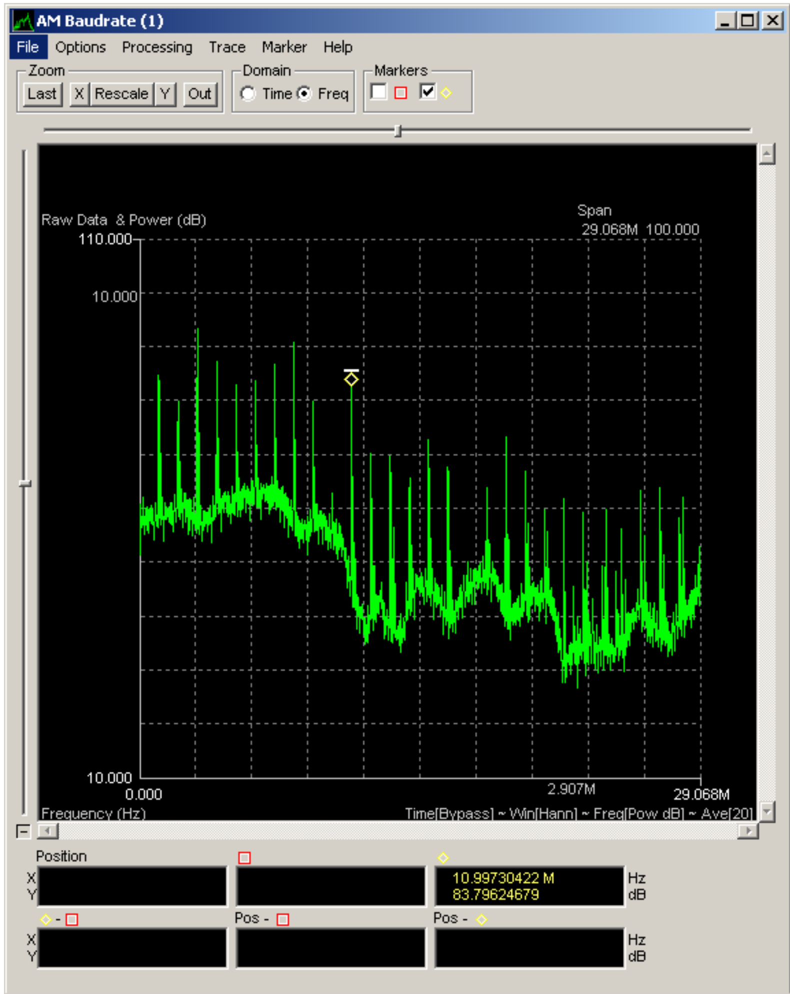


Figure 92. Baudrate detector display with 11Mb/s wifi1.wrd signal

Leave this display open. Next open the test point display after the I & Q Detector. The display will appear as below due to the center frequency not being specific.

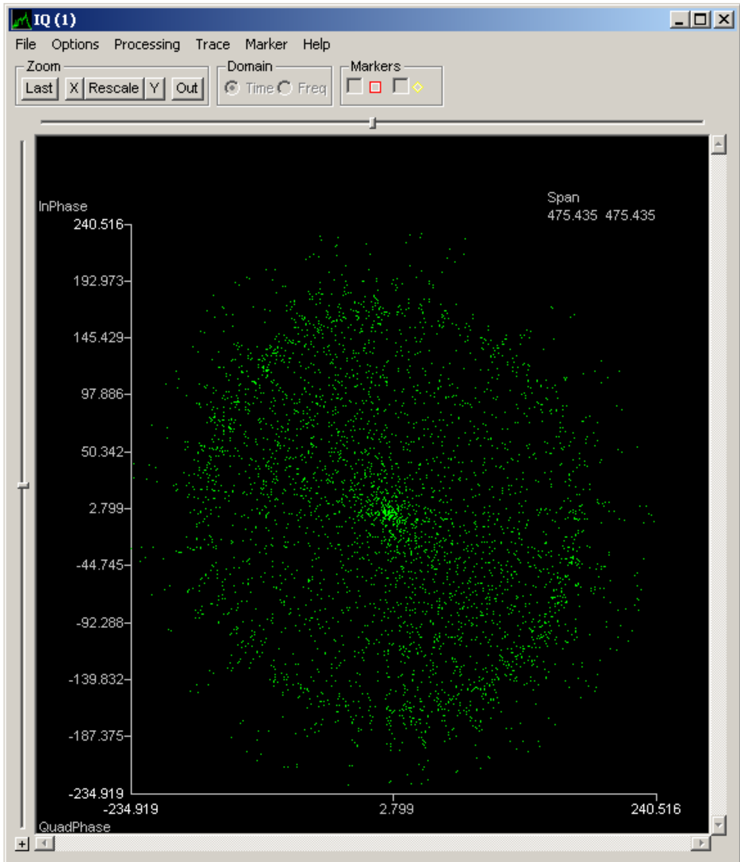


Figure 93. Inaccurate center frequency depicted in I&Q test point display

Leave this display open and select the Fixed button under Sub band tuner on the Preview window. Click on the Frequency button on the Fixed Sub band Tuner window. Using the frequency adjustment window, vary the frequency slightly to create a change in the appearance of the IQ display. The intent is to stop the spinning appearance on the display. Change the measurement units on the Frequency window to Hz. Start from the fourth column from the left and begin making changes to the frequency. Keep moving right and adjust the frequency to slow down and eventually stop the signal in the IQ display. The resulting display will be similar to Figure 94.

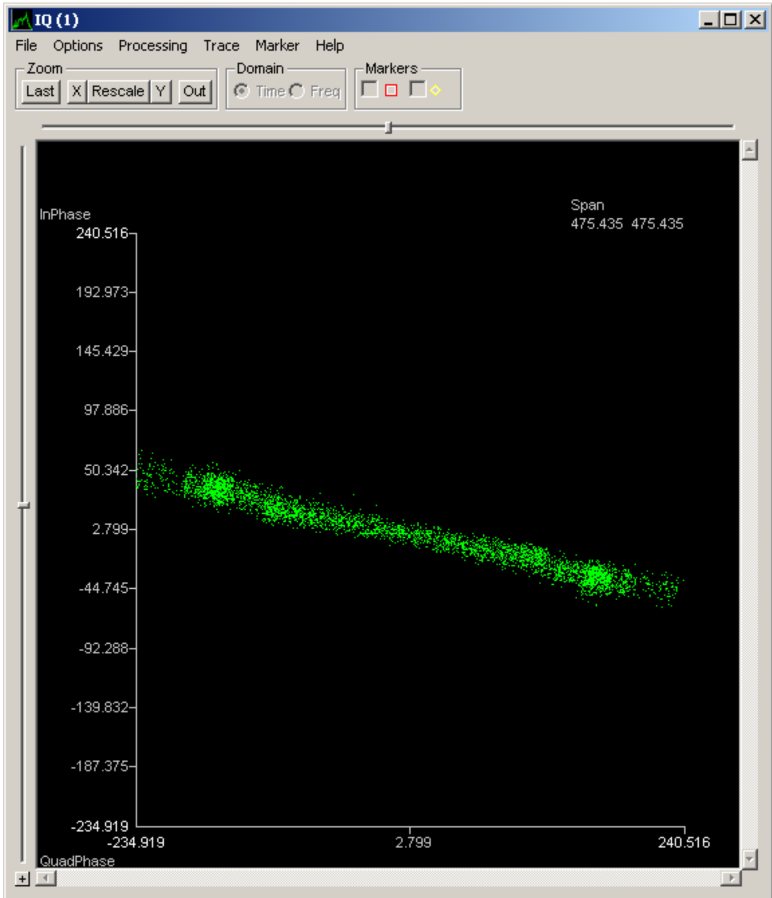


Figure 94. IQ display with adjusted frequency

This signal is ready to export to the Demod application. From the Preview window, select "File," then "Export/Save for Demod." Make sure that the center frequency the appears in the Export/Save for Demod window is the same as what was just adjusted in the Sub band Tuner. If it is not, use the pull down menu next to the Center Frequency line to select the correct center frequency. In the bottom half of the Export/Save for Demod window, checkmark Save Modulation Type and select PSK Normal with type "2 Phase."

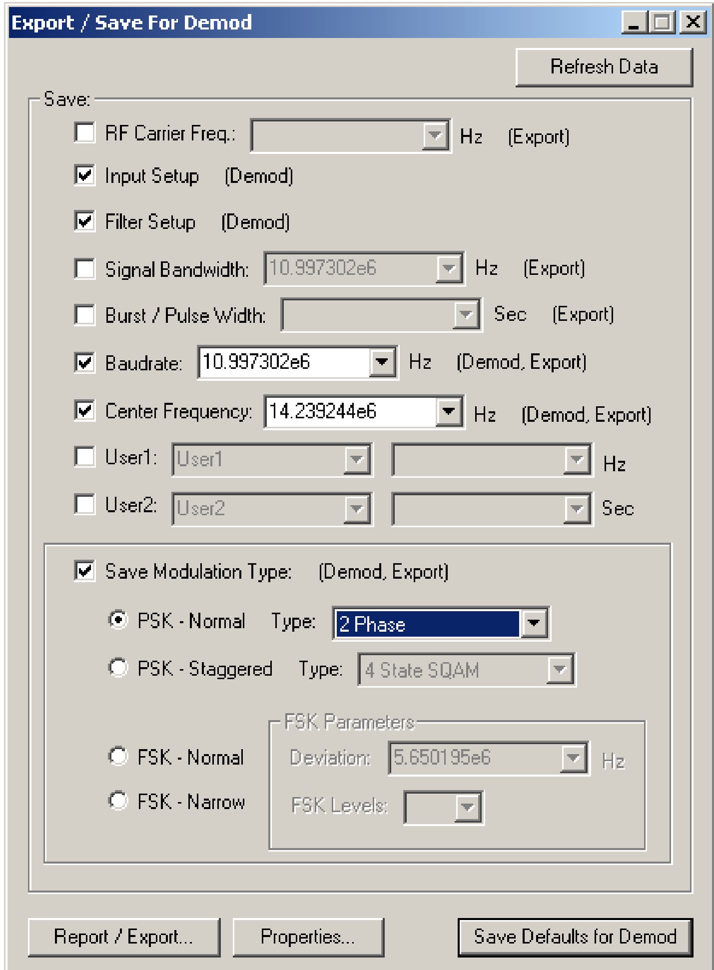


Figure 95. Export/Save for Demod window

Once this has been completed, select Save Defaults for Demod. Close the Preview window and all subordinate windows.

C. ADDITIONAL WIFI ANALYSIS WITH DEMOD

1. Procedural Guidance

Using the Demod application within Signalworks®, this wireless signal can be demodulated down to the bit level allowing the analyst to break out the Media Access Control (MAC) address.

2. Advanced Analysis with the Signalworks® Demod Application

Open Demod either by double-clicking on the icon, or by selecting it from the Program menu. Do not hold Shift. Demod will open with the parameters from Preview already loaded. Close the Tip of the Day window. Click on the play button to start the signal playback. Click the Bypass button under Automatic Gain Control (AGC) and select Limiter from the list of options. This prevents distortion by setting a threshold level and compressing any signal energy that goes above that threshold. Open the test point after the Mixer. The display should resemble the signal represented in Figure 96.

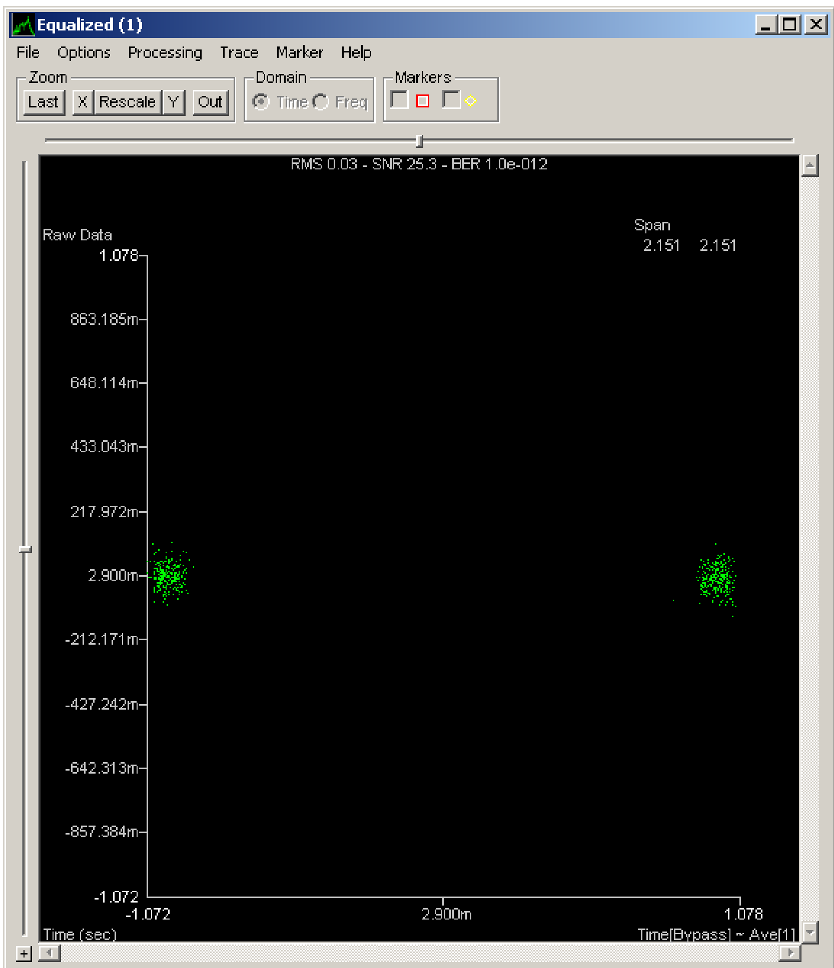


Figure 96. Mixer test point display of wifi1.wrd in Demod

At this point, the signal is prepared to be analyzed at the bit level. Open the test point after Bit Data in the Demod window. The display will resemble Figure 97.

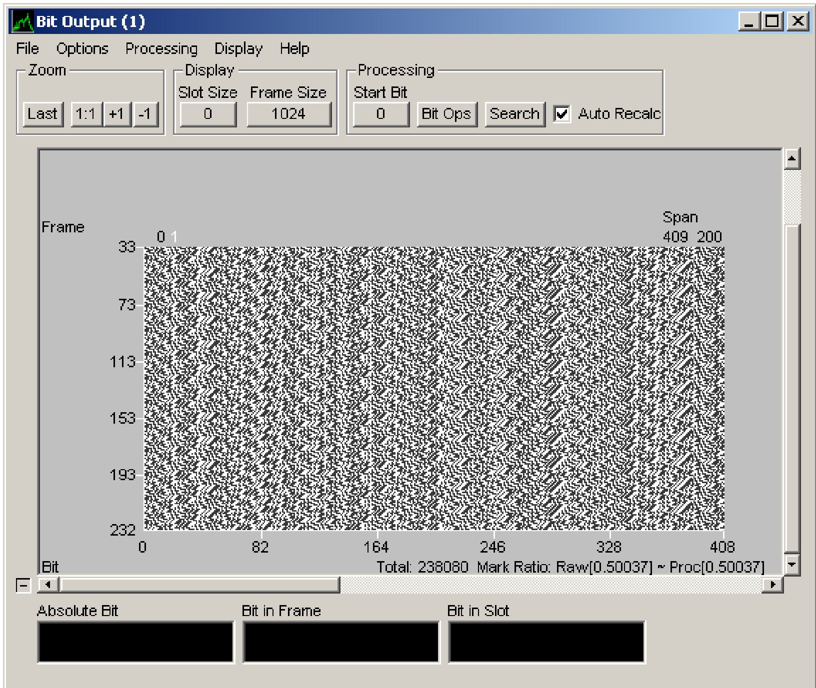


Figure 97. Bit Operations display for wifi1.wrd

Click on the Bit Ops button in the Processing section of the Bit Operations display. The window that opens is the Bit Operations Editor. Click and drag the Keep/Skip tool from the left menu on the left into the Applied Operations window on the right side. Click once on the Keep/Skip tool that was just placed in the Applied Operations to pull down the expanded functions. In order to remove the Walsh coding from this signal, the Keep/Skip must be set to keep one and skip twenty-one. Put the cursor in the window and change the Keep/Skip setting to "(1, 21)."

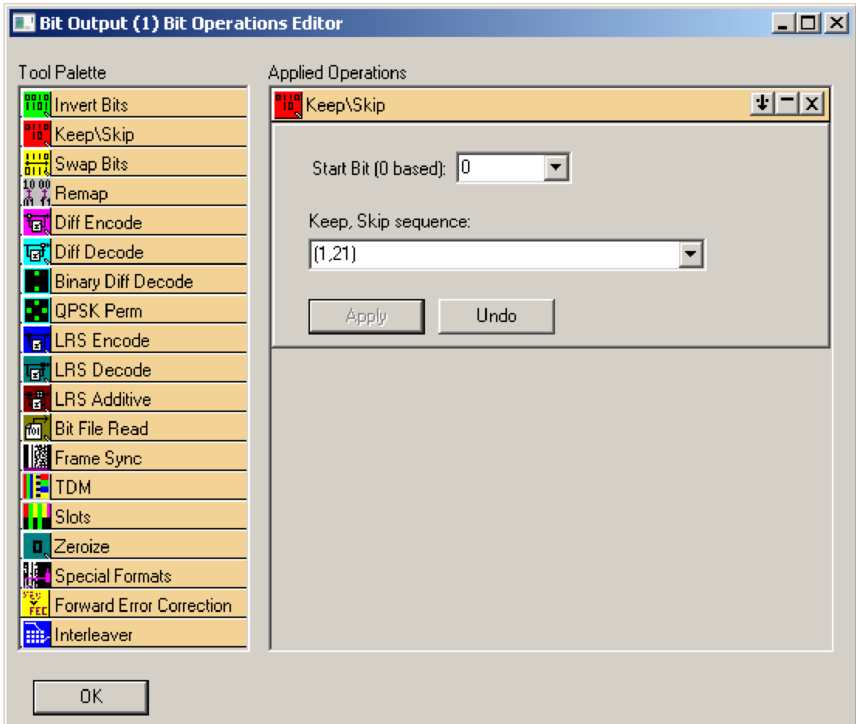


Figure 98. Bit Operations Editor with Keep/Skip tool with expanded functions

Click on the apply button to save the Keep/Skip settings. This window will be used later and can be minimized for now.

On the Bit Operations display, select Processing from the top menu and then select Search and Scan. Click on the Linear Recursive Sequence tab and click the LRS Quick Scan button.

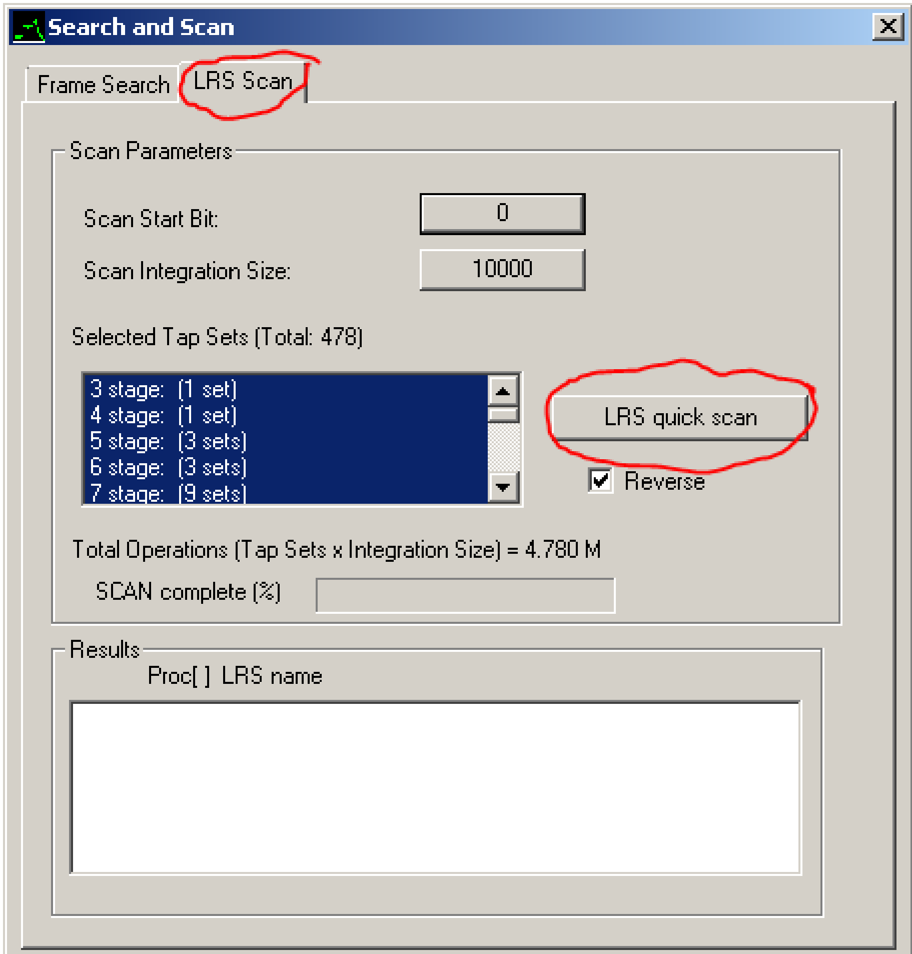


Figure 99. Search and Scan window with LRS tab selected

Upon clicking on the LRS quick scan button, a window will pop up titled LRS scan correlation. There should be a single spike indicated on this display, as depicted in Figure 100.

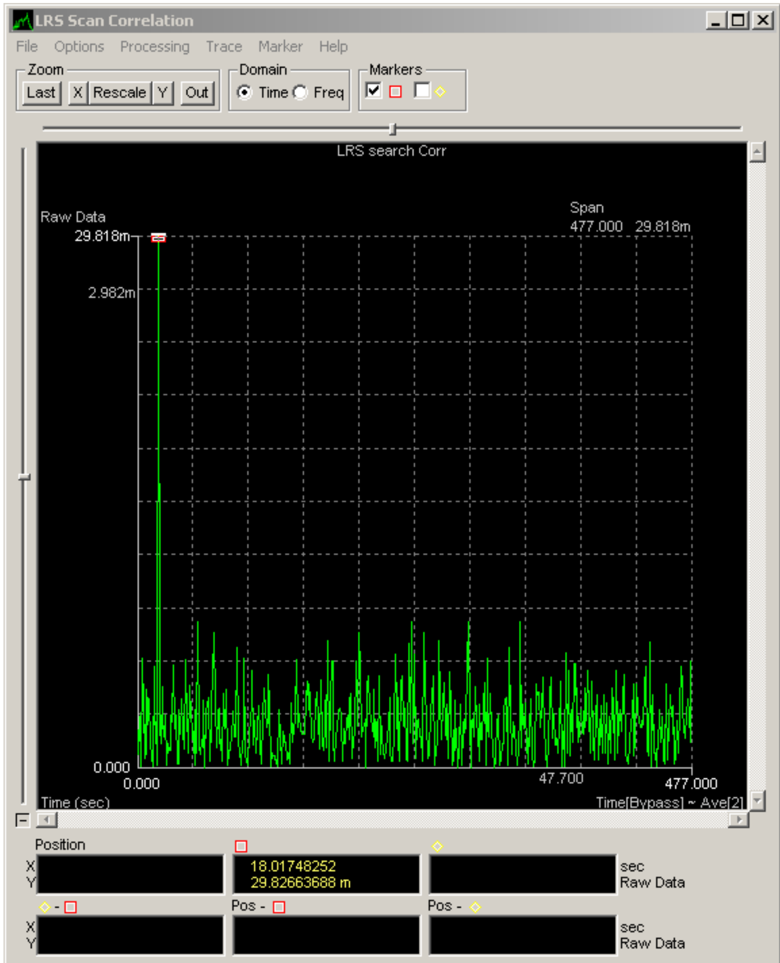


Figure 100. LRS Scan Correlation with single spike

Once the single spike has been verified, close this window and return to the Search and Scan window. At the bottom of the window, there should now be a list of results. Double click the result “R7+R4+1.”

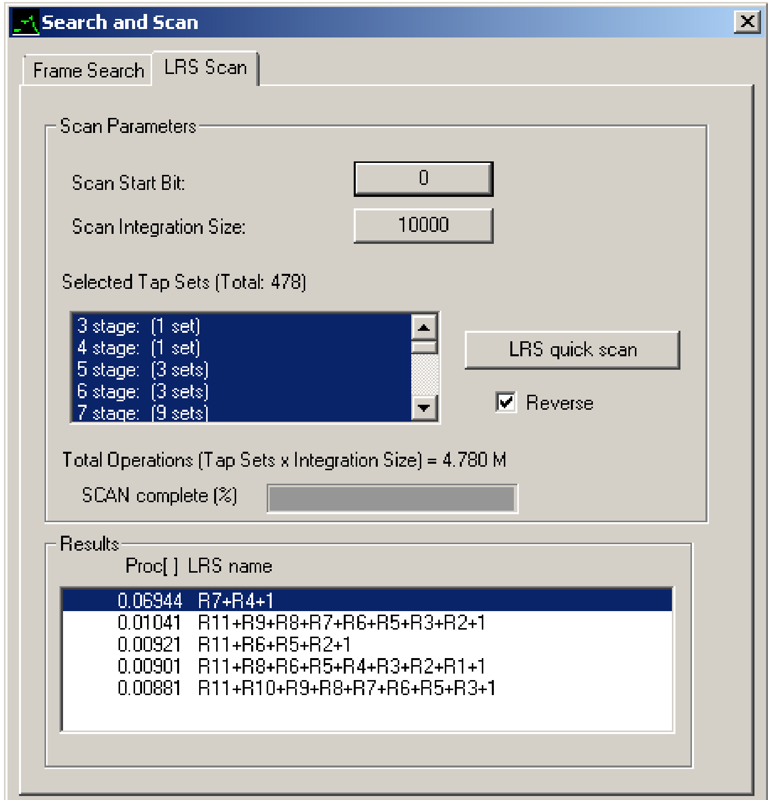


Figure 101. Search and Scan window with populated Results

This automatically places the LRS Decode tool into the applied operations side of the Bit Operations Editor window. Maximize the Bit Operations Editor window to verify the LRS Decode tool is now in the applied operations list. Click on the LRS Decode tool to pull down the details, if it is not already visible, and then select the Apply button.

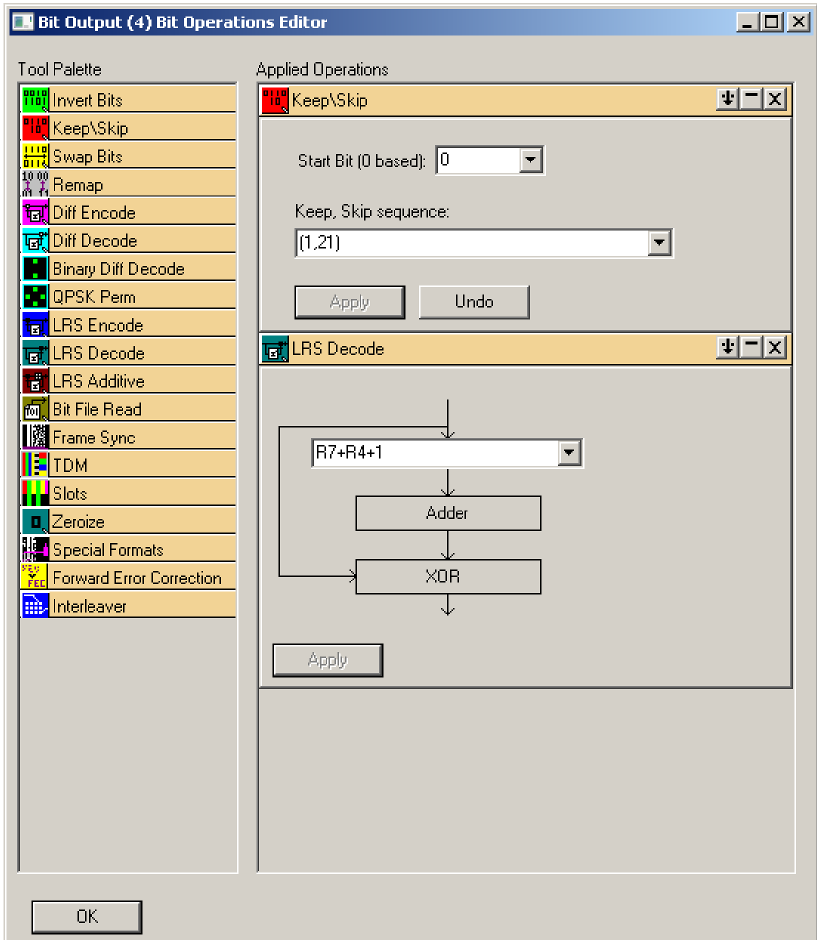


Figure 102. Bit Operations Editor with LRS Decode tool applied

Maximize the Bit Output window. Adjust the Frame size by clicking on the Frame Size button. Adjust the frame size to 48. The standard address frame for an 802.11b signal is 48 bits long. The display should look similar to Figure 103.

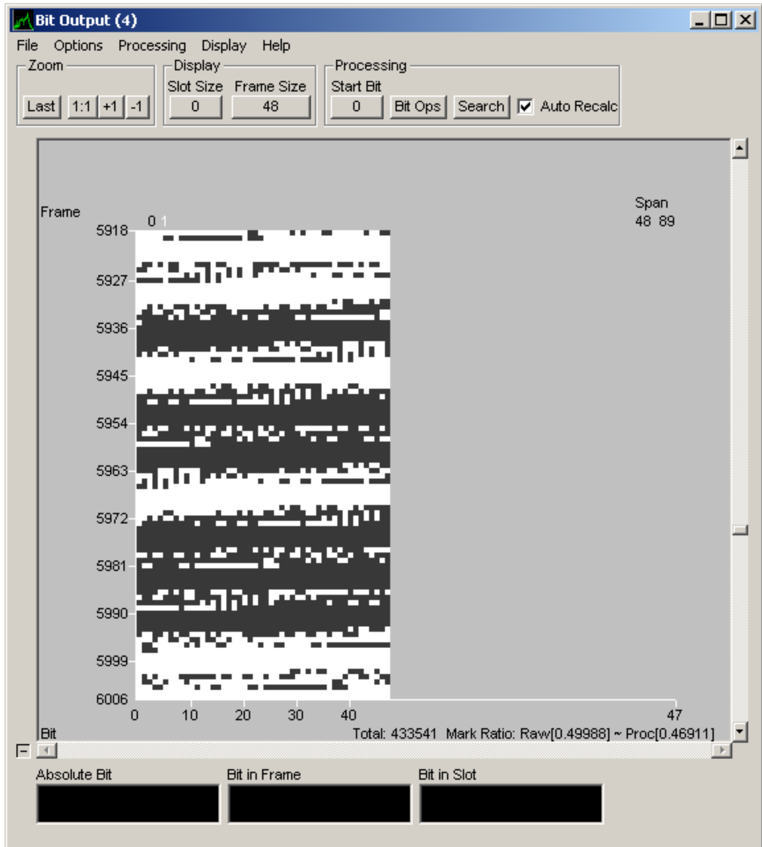


Figure 103. Bit Output display with 48 bit frame size

Select Display at the top of the Bit Output window and select "4 Bit 0-F Hex." The display of bits will change to hex characters and should resemble Figure 104.

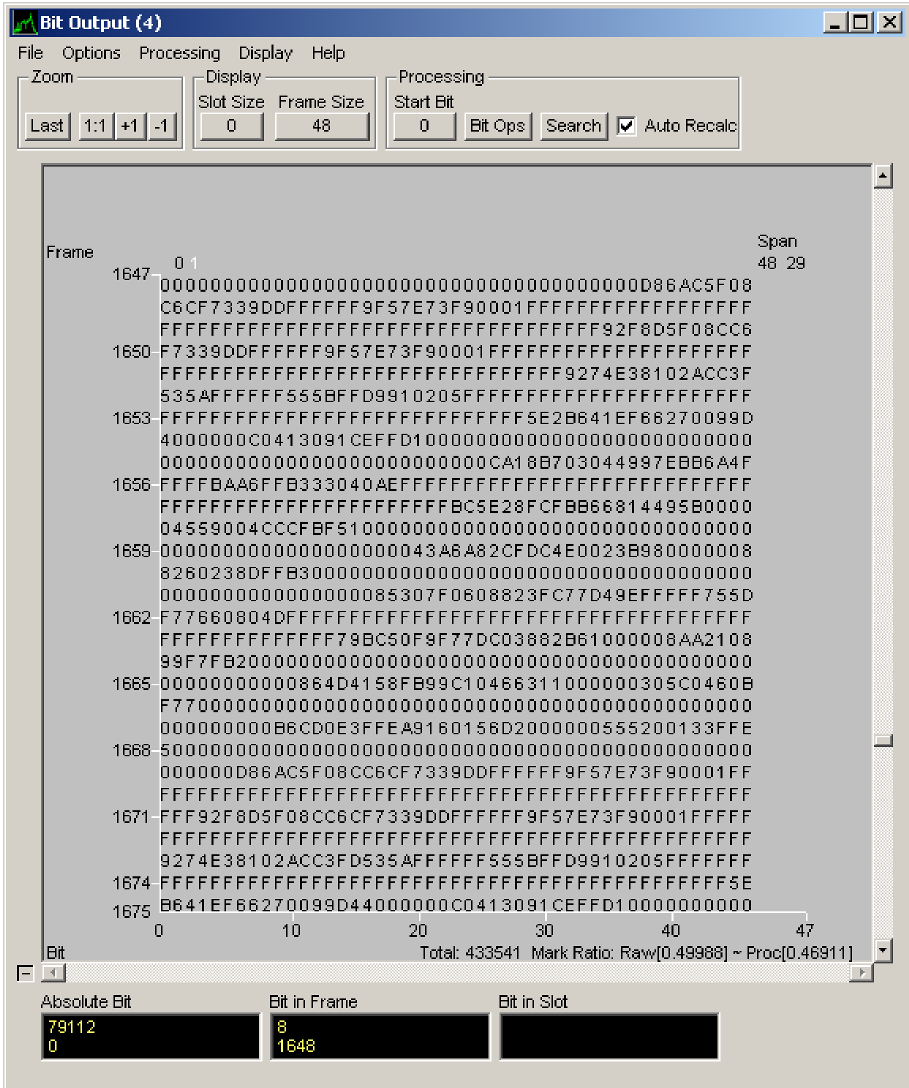


Figure 104. Bit Output with 0-F Hex display

At this point, the MAC address of the computer sending traffic can be determined by locating the first twelve characters after the string of "F" characters. Figure 105 highlights a few MAC addresses following strings of F characters.

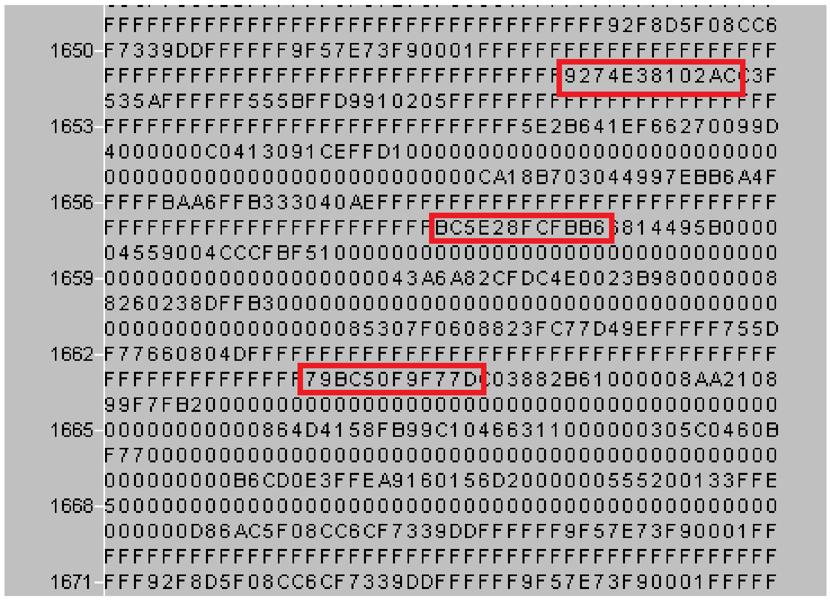


Figure 105. HEX display with highlighted MAC addresses

D. WIFI ANALYSIS RESULTS

This process dealt with a sample file of an 802.11b standard WIFI signal that is resident along with other sample files in the normal Signalworks® installation. Since the signal had periods of transmit and periods of idle, the time frame of the signal file to import into Preview was specified using Start and Stop settings so that only periods of transmit were analyzed. There were a few differences in the procedure for this signal that were done to highlight different features of Signalworks®. Instead of estimating a band center, a filter was used to exclude all but the peak energy of the signal. The analyst also looked at the I&Q display in Preview to make a frequency adjustment of the center frequency. Within Demod, the analyst worked down to the bit level and derived the MAC address of computers sending traffic.

VI. SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

A. SUMMARY

1. Installation and Operation

For the duration of this project, Signalworks® 4.0 was installed on a Compaq V2000 laptop computer with 32-bit Windows Vista operating system. The laptop processor is an AMD Turion 64-bit chip operating at a speed of 1.8GHz with two gigabytes of RAM. This exceeded the minimum requirements specified for Signalworks®. Specifications state that as little as 128Mb of RAM are acceptable. Specifications also state that Signalworks® can be installed on other Windows platforms including Windows XP and Windows NT as well as Linux. These alternate operating system configurations were not tested during this project.

Installation was simple and straightforward. Inserting the CD-ROM into the laptop resulted with the install utility initiation then progressed through the install steps. A license key was provided by Signami-DCS specifically for Windows Vista.

Signalworks® operated without flaw and featured intuitive window controls and menu options. There were a few instances where the video would become choppy or freeze during signal playback at normal speed. This would likely be overcome by today’s faster processors that are nearing three-gigahertz speeds. A separate vice-integrated video card would provide additional enhancement to video playback. This issue had no impact on analysis.

Signalworks® does not come with a manual describing how to use the application. It does include a series of tutorials within the help tool, which provide detailed walk-through procedures to highlight the main features of SignalGen, Preview, and Demod. When additional help was needed, the help tool included an indexed search function to find specific help topics. Support from Signami-DCS was excellent, and was utilized extensively through this project. E-mail

correspondence was the major communications method to address questions; however, phone calls and online collaboration tools were used to when the need demanded.

2. Capabilities and Limitations

The constraints of this project did not require utilization of the full capabilities of Signalworks®. For the limited purpose of determining center frequency, baud rate, and modulation technique, Signalworks® proved extremely capable when analyzing phase-shift keyed, quadrature phase-shift keyed, and quadrature amplitude modulated signals. Bit analysis was equally successful as seen in the WIFI example. All operations within Signalworks® are menu- or window-driven. There is no need for programming or script writing during any of the procedures detailed during this project.

3. Findings

The original goal of this project was to conduct a test of Signalworks'® capabilities to exploit Orthogonal Frequency Division Multiplexed signals, specifically those based on the IEEE 802.16 Wireless Metropolitan Area Network (WMAN) standard known commercially as WiMAX. As research developed, it became apparent that Signalworks® did not have the capability to demodulate an OFDM signal. Signalworks'® wireless capability is limited, at the time of this project, to 802.11b WIFI signals. In the previous chapter, an 802.11b signal was demodulated and analyzed to exploit MAC addresses in the transmitted content. What was apparent, and amplified, as the course of this project developed, was that Signalworks® could be a valuable tool for use in an academic environment. Using Signalworks® to aid in comprehension of digital communication signal characteristics, and the application of some classroom theory, would provide positive reinforcement of key theoretical concepts. As an academic institution, however, it is key to maintain a forward leaning approach to technology research. The prevalent standard for wireless communications today is 802.11g; 802.16 is an up-and-coming competitor in several markets. Not having the ability to exploit

and analyze either of these IEEE standards is a detriment to Signalworks® as a signals analysis solution for the Department of Defense and its academic research. The IEEE 802.16 family of WMAN signals is considered a key technology enabler for widespread wireless access to the Internet (Ahson and Ilyas 229). This is particularly important throughout developing countries where telecommunication infrastructure is slow to develop due to geographic obstacles or fiscal limitations. In such areas, it is preferential to install wireless networks to overcome terrestrial link deficiencies and vast installation costs.

The result of this project was a comprehensive guide to using Signalworks® to generate and analyze signals. Appending this guide to include procedures for processing WiMAX signals would involve little effort. The steps followed would closely resemble those used for PSK, QPSK, QAM, and WIFI. Should Signalworks® develop the ability to exploit WiMAX signals, this guide has already established the template for processing those signals. For current use, this guide offers a systematic instructive tool for analysts or students who are first-time users of Signalworks®.

B. RECOMMENDATIONS FOR FUTURE WORK

As Signalworks® continues to develop advanced algorithms to process new signals such as IEEE 802.16 WiMAX standards, future projects demand detailed procedures for processing such signals. This will aid students in understanding WiMAX by walking them through processing a signal. Until that capability is developed, there may be benefit in employing current features of Signalworks® to attempt exploitation of sample 802.11g or 802.16 files. Although the developers of Signalworks® have stated that demodulating these signals is not supported by version 4.0, manipulating the signal in Signalworks® may illuminate some unintended capabilities.

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